Farmers' risk exposition and its drivers

Duden, C., Offermann, F.

Thünen-Institut of Farm Economics, Braunschweig, Germany

christoph.duden@thuenen.de, frank.offermann@thuenen.de

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c.duden@thuenen.de, frank.offermann@thuenen.de

Abstract

The analysis of income risk is the basis for farm risk management. However, comprehensive overall risk analyses are often scarce, e.g. for Germany. The present study analyses risk exposure for more than 3,000 farms in Germany in the period 1996/97-2015/16 on the basis of the national FADN data. We use the coefficient of variation, variance decomposition and robust regression techniques to quantify risk exposure and its drivers. Our results show that (i) risk exposure is heterogeneous, (ii) farm income risk increased in the period after 2007 for many farms, especially arable and dairy farms, and (iv) the return on sales decreases farm income risk substantially.

Keywords: Risk Exposition, Income Risk, Farm Level Risk, Risk Components

JEL Code: Q12, Q14, Q15

1 Introduction

Business and especially farming have always been risky. However, risks for European as well as German farmers are widely believed to increase, due to an expected rise of extreme weather events as a consequence of climate change (Trnka *et al.*, 2014; Gömann *et al.*, 2015) as well as further market liberalisation and the increased exposure to the variability of world market prices (Ledebur and Schmitz, 2012; Filler *et al.*, 2010; Keane and O'Connor, 2009; European Commission, 2017b). Also, the risk increasing effect of changing farm characteristics is discussed, e. g. decreasing profits per output and the increasing use of external production factors (like borrowed capital) (Vrolijk *et al.*, 2009). These changes need to be adequately addressed by risk management to limit the danger of illiquidity of the farming business and/or severe reductions of the consumption possibilities of the farm household. The first step in this process is the analysis and quantification of risks (Kunreuther, 1976; Mußhoff and Hirschauer, 2016). The quantification of one's exposure to risk is a precondition to measure changes in risk, to set goals, compare farms and evaluate risk management instruments. However, quantifying risk is often methodologically challenging.

Whereas risk exposition describes each farmer's risk[1], existing literature however overwhelmingly focusses on risk at aggregated level, e.g. national prices or regional yields. Finger (2012) and OECD (2009) stress that the assessment of risk faced by farmers requires data of individual farmers because the aggregation of economic independent farms can lead to crucial underestimation in risk. The few studies which examine risks at farm level are often restricted to the isolated analysis of specific aspects, e.g. yields (Gömann *et al.*, 2015; Heidecke, Offermann and Hauschild, 2017; Lüttger and Feike, 2018; Albers, Gornott and Hüttel, 2017) or prices (Ledebur and Schmitz, 2012; Keane and O'Connor, 2009; Filler *et al.*, 2010). For three reasons it is important to follow a holistic approach instead of just a single risk component approach in farm risk analysis. First, an event is only relevant if it has an impact on overall

[1] The term „risk exposition" originally referred to quantifying agents' risk expressed in units of money on stake (Adler and Dumas, 1984). However, the recent literature widened the term to a concept of objectively describing and measuring the main risks and uncertainties affecting an economic agent, based on the expected distribution or variability of income or its components (OECD, 2009).

targets (e.g. level of income variability). Second, the risk of an economic target value like farmers' income is the result of different risky components –like price and yields– which are crucial individual parameters to control the risk of the overall target (Markowitz, 1952; Turvey, 2012; de Mey *et al.*, 2016). Thus, the analysis of just income risk alone is also not sufficient to facilitate the comprehension and the management of the risks faced. Third, different risk components, especially prices and yields, are interdependent which can influence the level of risk substantially (Kimura, Antón and LeThi, 2010). A whole farm approach is especially relevant if farms are diversified. Managing risk on a single risk component basis and ignoring whole-farm consequences may result in increasing risk rather than decreasing it (Doms *et al.*, 2018; Mußhoff and Hirschauer, 2016).

A major problem is that the availability of historical time series of individual household data for farmers is very limited. Only a few countries in the Farm Accountancy Data Network (FADN) like the Netherlands, Switzerland and the UK have this data (de Mey *et al.*, 2016). Even if one focuses on farm-level income only, data is limited (OECD, 2011), and studies are often based on less than ten years of observations (El Benni and Finger, 2014; Tribl and Hambrusch, 2012; Bahrs, 2011; Severini, Tantari and Di Tommaso, 2017; Severini, Biagini and Finger, 2018; de Mey *et al.*, 2016). Thus, empirical studies at farm-level, which cover income risk and its interactions with drivers like yield and price fluctuations are rare, particularly in peer reviewed journals, even though such analyses are generally recommended (OECD, 2009).

The results of farm-level risk analysis show that farm income risk differs between farm types (Vrolijk *et al.*, 2009; Tribl and Hambrusch, 2012; European Commission, 2017a; Severini, Biagini and Finger, 2018; Pigeon, Henry de Frahan and Denuit, 2014; Poon and Weersink, 2011). Among different farm types the highest income risk is observed in intensive livestock production (EU-wide study by VROLIJK *ET AL.*, 2009; European Commission, 2017a) or in crop production (Austrian study by TRIBL AND HAMBRUSCH, 2012). However, differences between farms of the same farm type are substantial, too.

In addition to the factor "farm type" a variety of other factors which influence farm income risk are discussed in the literature. There are several studies which analyse the influence of individual farm characteristics in the USA, Canada, Switzerland and Italy empirically (Barry, Escalante and Bard, 2001; El Benni, Finger and Mann, 2012; Poon and Weersink, 2011; Severini, Tantari and Di Tommaso, 2017). The results of these studies indicate that the degree of specialisation decreases farm income risk, while the findings with respect to the effect of farm size differ between studies. Also, the geographical location (region) of the farms has a major effect on farm income risk (El Benni, Finger and Mann, 2012; Severini, Tantari and Di Tommaso, 2017). In addition, it is argued that the return on sales, i.e. the profit per unit of output, (Vrolijk *et al.*, 2009; Mußhoff and Hirschauer, 2016), and the use of external production factors (Vrolijk *et al.*, 2009) are influencing farm income risk, though to our knowledge no empirical analysis of these relationships exists. Existing analyses often concentrate on analysing the existence and direction of influencing effects, while less attention has been paid to identifying the relevance of the different effects.

Most known studies conducting comprehensive farm-level risk analysis use data from 2009 or older. Since a structural break in price development on agricultural markets occurred after 2007 (Ledebur and Schmitz, 2012; Keane and O'Connor, 2009; Tadesse *et al.*, 2014; Piesse and Thirtle, 2009; World Bank, 2012), it remains an open question if and to what extent these changes had an impact on farmers' risk exposition. For Germany –a country of 250,000 farms– only one comprehensive risk analysis across different regions and farm types based on recent data is known (European Commission, 2017a). However, farm characteristics and the decomposition of income risk in its components has not been conducted for Germany even though climatic and economic conditions differ from those in other countries.

This paper focuses on the analysis of the risk environment of farm firms. However, in agriculture the farm household is often considered the decision-making unit, and thus risk assessment and management will be determined by the household objectives, household resources (assets, income sources) and household adaption possibilities (e.g. shifting investments or consumption over time, accumulating or depleting savings, OECD, 2009). The existence of off-farm income may lead to household risk balancing, which de

Mey *et al.* (2016) found to be a prevalent strategy in smaller farms in Switzerland. As the available data for Germany does not include reliable information on the level of off-farm income, we restrict our income risk analysis to full time farms, where the importance of farm income for total household income is generally higher. The observed risks at farm-level are important information for risk management on household level, even when there is off-farm income. Normative recommendations regarding risk management strategies, which are beyond the scope of this paper, however need to take into account off-farm income as well as individual risk preferences and objective functions.

Against this background, the overall objectives of this paper are to provide a quantification of farm-level income, price and yield risk for German farms pre- and post 2007, and to identify and quantify the influence of farm characteristics on farm income risk. For the analysis we use a multi-year data set over 3,000 farms for the years 1996/97-2015/16, provided by the Farm Accountancy Data Network (FADN) of the Federal Ministry of Food and Agriculture of Germany. In addition to farm income risk, we analyse price risk for 13 and yield risk for eight agricultural products. We quantify the realized (observed) risk by measuring the fluctuation with the coefficient of variation. We calculate the contribution of revenues and costs to the overall income risk. By comparing the periods 1996/97-2005/06 and 2006/07-2015/16, we determine how risks have changed over time, i.e. how risk levels differ between the ten periods before and after the year 2007, which is the year of structural break on agricultural markets. Relevant farm characteristics which drive farm income risk are identified with a cross-sectional approach. For this purpose, we focus on characteristics that can be influenced by the farmer. We confirm robustness of our results by applying robust statistical measures.

Our strategy is as follows: First methodology and data are described. Afterwards we present our results starting with risk measures for prices, yields and farm income risk for different products and farm types, respectively. We then quantify the effect of farm characteristics on the farm income risk before decomposing farm income risk into revenue and cost components. The paper ends with our discussion and conclusions on risk analysis of German farms.

2 Method

Given the widely accepted probabilistic definition of risk (OECD, 2009; Chavas, 2004; Mußhoff and Hirschauer, 2016), risk is characterized by the distribution of all possible outcomes and their probabilities. Typically, the distribution is measured based on the deviations from the central tendency, i.e. expectation (Just and Rausser, 2002). For this purpose, we describe how the expected value is formed and how we measure risk based on expected value formation. We then outline our methodological approach to estimate the influence of farm characteristics on farm income risk, and explain how the contribution of risk components (e.g. sales revenue and material costs) to farm income risk is measured.

2.1 Measuring risk

2.1.1 Formation of the expected value

For yields it seems reasonable to assume that farmers are aware of long-term trends due to technical progress and environmental changes. Thus, farmers' expectation is formed by detrending yields with a linear trend[2] (Pelka and Mußhoff, 2013; Vrolijk *et al.*, 2009). Our time series variable, in this case yield, of farm i in year t is denoted by x_{it}. We estimate the yearly change of yield b_1 for aggregated mean yield over all farms in year t $\overline{x}_t$ with MM regression (Yohai, 1987): $\overline{x}_t = constant + b_1 * t + e_t$. The error term is denoted by e_t. MM regression is a robust estimation technique downweighting outliers which leads to more precise trend estimations especially for short time series (Finger, 2010b). To account for the

[2] While some studies apply flexible polynomial models (Just and Weninger, 1999) or quadratic models (FINGER, 2010A), we use a linear trend for our study because our time series is too short to estimate long term changes in trend growth rates.

individual farm-level yield level we take into account a relative trend b_{i1}^{rel} (equation (1)) calculated with the mean yield of farm i over all years $\overline{x}_i$. Equation (2) shows the expected value formation based on the aggregated trend with the estimate b_{1i}^{rel} to the reference year t^*, which is the mean year of each time period. This expected value is the same for all years of a period. The expected value of x_{it} based on the aggregated detrending is denoted as $E(x_{it})^{trend,aggregated}$.

$$b_{1i}^{rel} = \frac{b_1}{\overline{x}} * \overline{x}_i \tag{1}$$

$$E(x_{it})^{trend,aggregated} = \frac{1}{T}\sum_{t=1}^{T} x_{it} + (t^* - t) * b_{1i}^{rel} \tag{2}$$

Prices and incomes are deflated by the consumer price index provided by STATISTISCHES BUNDESAMT (2017B). Expected values of income and prices also formed with a linear trend. The linear trend is based on the assumption that the farmer is able to derive a long-term trend for a certain period. While the linear trend for aggregated prices is derived equivalent to yields (equation (2)), detrending of income is based on farm-individual trend to account for farm individual factors (Vrolijk *et al.*, 2009). An individual trend is generated by MM regression: $x_{it} = constant_i + b_{1i} * t + e_{it}$. Expected value $E(x_{it})^{trend,individual}$ is calculated as:

$$E(x)_{it}^{trend,individual} = constant_i + b_{1i} * t \tag{3}$$

Linear detrending is widespread, straightforward and comprehensible, but there are also other methods like the adaptive expected value formation or the expected value formation by ARMA-processes (Nerlove and Bessler, 2001). The adaptive expected value formation is based on the assumption that farmers apply a simple heuristic and predict the future based on the past ('naïve' expectations). ARMA-processes assume that farmers know the stochastic process, i. e. autocorrelation and cyclical patterns. Nevertheless, we follow the majority of studies and apply linear detrending because of four reasons: First, the linear detrending approach allows us to use the full time series of observations, whereas the adaptive expectation method would imply loosing observations of the already not very long time series of 20 years. Second, adaptive expected value formation yields results qualitatively similar to linear detrending (Duden and Offermann, submitted). Third, the extent to which farmers are able to consider autocorrelation or cycles in their planning is discussed controversially in the literature (Parker and Shonkwiler, 2014; Berg and Huffaker, 2015). Finally, available time series are too short to reliably taking into account cyclical patterns with ARMA-processes (Box and Jenkins, 1970).

2.1.2 Coefficient of variation

We measure the risk with the coefficient of variation. The coefficient of variation (CV) is a measure of fluctuation. It is calculated as the standard deviation σ_{x_i} divided by the mean expected value of farm $\overline{E(x)}_i$, and thus is a relative measure which facilitates comparisons of fluctuations between different samples and variables as it is independent of scale. We choose the CV because it allows to measure fluctuations around the expected value and is widely used in the literature (e.g. El Benni and Finger, 2014), which facilitates the comparison of our results to those of other studies.

An alternative risk measure is the shortfall probability which focuses on the risk of loss. However, we opt for the CV because it takes account of positive and negative fluctuations (i.e. it corresponds more closely to the definition of risk used in literature; e.g. cf. OECD, 2009). For an analysis of farm risk based on short fall risk measures see e.g. Duden and Offermann, submitted).

2.2 Measuring influence of farm characteristics

In order to analyse the influence of farm characteristics on the CV of farm income, we first identify factors, then hypotheses about their effect are derived as well as indicators for measuring farm characteristics are determined. Finally, we develop an econometric model.

2.2.1 Factors, hypothesis and indicators

In a literature search we identify the return on sales, the degree of specialisation, the farm type, the use of external production factors and farm size as influencing factors on the farm income risk (Barry, Escalante and Bard, 2001; El Benni, Finger and Mann, 2012; Poon and Weersink, 2011; Severini, Tantari and Di Tommaso, 2017; Vrolijk *et al.*, 2009; El Benni, Finger and Meuwissen, 2016; OECD, 2009). In addition, we control for direct payments, the region, the age of the farmer and region-specific socioeconomic characteristics.

Return on sales. Small market returns, i.e. sales revenues over (paid) costs - intermediate consumption of inputs, depreciation, paid labour, interest and rents[3], in combination with high revenues, implicate that small revenue fluctuations result in large income fluctuations (in terms of relative fluctuation) (Vrolijk *et al.*, 2009; Mußhoff and Hirschauer, 2016). This leverage effect is reduced by increasing the profit per unit of output. We expect that an increase of the return on sales decreases farm income risk.

External production factors. The use of borrowed capital, leased land and external labour is generally associated with fixed payment obligations, which must be met irrespective of the economic situation of the farm. The use of the company's own production factors, on the other hand, does not require any payments that burden the company's profit, or, in the case of the company's own production factors, the factor remuneration can be adjusted annually to the economic situation of the farm. The use of external production factors is measured by the ratio of external work units to total work units, the ratio of leased land to total utilised land and the debt ratio. We expect a higher ratio of external production factors is resulting into higher farm income risk.

Degree of specialisation. A higher degree of specialisation in one or a few outputs, i.e. a lower degree of diversification, reduces the risk balance between different outputs. In view of the many ways in which a farm can specialise, we measure specialisation at the three levels:

a) Specialisation regarding on-farm agricultural production (component 1, details see point b) and on-farm non-agricultural production (component 2, sum of e.g. trade, services, biogas),
b) Specialisation regarding branches of agricultural production (consists of the following components: (1) plants without vegetable, permanent crops and other special crops, (2) horticulture, (3) permanent crops and other special crops, (4) pigs, (5) poultry, (6) dairy, (7) other cattle as well as (8) other animals),
c) Specialisation regarding crops (consists of all plant species, e.g. (1) winter wheat, (2) winter barley, etc.), in addition, we add a separate factor (interaction variable) for the specialisation regarding crops only for crop farms, because we expect this effect to be higher for this farm type.

To measure specialisation, we use the Herfindahl index HI of sales revenue X for C components (cf. El Benni, Finger and Mann, 2012), which is calculated as:

[3] Calculated by subtracting direct payments from the income (accounting profit per farm)

$$HI_i = \frac{\sum_{c=1}^{C} X_{ci}^2}{(\sum_{c=1}^{C} X_{ci})^2} \quad (4)$$

The index is 1 for one output component and decreases to 1/C for equal distriubtion of sales revenue across all components. We expect that an increasing degree of specialisation (an increasing Herfindahl index) increases farm income risk.

Farm type. As we discuss in chapter 1, numerous studies have found differences in farm income risk between farm types, i.e. the type of specialisation. Indeed, differences between farm types should decrease in our (regression) analysis, since we control for other farm characteristics. This is because some characteristics are linked to farm types. For example, horticulture farms usually have a higher proportion of external labour. However, studies show considerable differences despite the extraction of farm characteristics (Severini, Tantari and Di Tommaso, 2017). In contrast to the existing studies, we also analyse the effect of return on sales. Hence, we expect the differences between farm types to decrease significantly, because farm types substantially differ in terms of return on sales (Vrolijk *et al.*, 2009).

Size. In debates about farm income risk, size is often an important issue. We argue that larger farms benefit from additional on-farm risk balancing. For instance, larger crop farms have a higher on-farm natural hedging due to distributing crops across a higher number of fields (Finger, 2012). Also, for other farm types we suppose that there is an equivalent form of on-farm natural hedging. Hence, we expect farm size to have a negative effect. However, we expect a small effect, because we control for the degree of specialisation with seperat variables (see above). The presumably small effect is confirmed by the fact that the observations in the existing literature are inconsistent, e.g. size has a positive (El Benni, Finger and Mann, 2012; Poon and Weersink, 2011; El Benni, Finger and Meuwissen, 2016) or a negative effect on income risk (Severini, Tantari and Di Tommaso, 2017; Barry, Escalante and Bard, 2001). For our study, farm size is measured using the standard gross margin. The standard gross margin, i.e. gross revenue minus special cost, is a measure for the economic size of farms (Eurostat, 2019). The gross margin is standardardised by valuing the individual scale of production (e.g. area in ha, heads of animal) by region specific uniform prices and costs.

2.2.2 Econometric model

We estimate the effects of risk factors X on the CV of farm income with a multiple linear regression, i.e. MM-estimation based on cross-sectional data:

$$CV = bX + e \quad (5)$$

The CV of farm income is measured based on expected values derived from a trend estimation. based on the period 1996/97 to 2015/16. We calculate the explanatory factors of each farm by taking arithmetic mean of the annual values. The estimated coefficients are denoted with b, the error term with e.

In contrast to other studies we do not use a panel estimation. While Barry, Escalante and Bard (2001) concluded in their study with 213 farms to prefer a panel regression because it increases the potential statistical significance, we follow Severini and use a cross-sectional approach, because first we have more observations than Barry, Escalante and Bard (2001) (N= 1,755) and second we do not loose time invariant information.

By using the MM-estimator (details see chapter 2.1) instead of an OLS-estimator, we ensure that our study is not biased through outliers (cf. Severini, Tantari and Di Tommaso, 2017). Also, we checked for heteroscedasticity and multicollinearity.

2.3 Measuring the influence of risk component variation

To identify sources of risks and starting points for effective risk management, we discuss how income risk is decomposed into its components sales revenue, other revenue, material costs and other costs. The variance of income can be decomposed into the variance of each additive connected component, i.e. variance of random variable X_c, plus the interaction between these components, i.e. covariance between X_c and X_d (Sachs, 2002):

$$Var(Income)_i = \sum_{c=1}^{C} Var(X_c)_i + \sum_{c=1}^{C}\sum_{d<c}^{C} 2Cov(X_{c,}X_d)_i \qquad (6)$$

Equation (6) shows the absolute extent of variance contribution. By dividing the absolute contribution of component c by the total variance of income we obtain the relative contribution of each component. The relative direct variance effect $direct(X_c)$ and the covariance effect, i.e. interaction effect $interact(X_{c,}X_d)$, are presented as a percentage of income variance:

$$\begin{aligned} 100\,\% &= \left(\sum_{c=1}^{C}\left(\frac{Var(X_c)_i}{Var(Income)_i}\right) + \sum_{c=1}^{C}\sum_{d<c}^{C}\left(\frac{2Cov(X_{c,}X_d)_i}{Var(Income)_i}\right)\right) * 100\,\% \\ &= \left(\sum_{c=1}^{C} direct(X_c)_i + \sum_{c=1}^{C}\sum_{d<c}^{C} interact\left(X_{c,}X_d\right)_i\right) * 100\,\% \end{aligned} \qquad (7)$$

2.4 Statistics and hypothesis tests

While risk measures and variance components are calculated for every single farm we evaluate the central value for the whole farm sample by using the 20 % trimmed mean. The trimmed mean is more suitable than the arithmetic mean when it comes to outliers, skewness or fat tails (Oosterhoff, 1994; Wilcox, 2017). A level of 20 % trimming results from a balance between information loss and robustness (Wilcox, 1996)[4]. We use the 20 %-trimmed mean rather than the median as it robust for our samples but the loss of power/efficiency is less than for the median.

Based on trimmed means, hypothesis tests are conducted while assuming that our sample is a random sample of the population in terms of risk exposition. In case of comparing different periods, methods and farm types we apply bootstrapped confidence interval based on the Yuen test (Yuen, 1974) for dependent and independent groups, respectively, which has been adopted in agricultural economics previously Finger (2012)[5]. The bootstrap (and trimmed mean) is chosen because it does not rely on distributional assumptions. The bootstrap method confidence intervals are derived from generating 599 new samples with replacement out of the original sample. A multiple group comparison which is needed for comparing expected value elicitation methods is applied by adjusting p-values with Holm's method (Holm, 1979).

Risk analysis is conducted with SAS 9.4, whereas hypothesis tests are implemented in R.

[4] A sensitivity analysis shows that our results are robust to different trimming values.

[5] See Wilcox (2017) for further details. In addition, a verification of results is conducted with the Wilcoxon sign rank test (Wilcoxon, 1945) and Wilcoxon sum rank test, respectively, comparing the median of sample distribution.

3 Data

Risk analysis is done with data of the national FADN provided by German Federal Ministry for Food and Agriculture. The stratified and unbalanced sample includes 20 years of data (1996/97-2015/16[6]). FADN-farms are selected in order to represent farm groups of a country (defined by economic size, farm type and region). The farm accounts include farm-level financial data and physical data. More than 10,000 German farms are included in the sample each year. The composition of the sample changes every year due to changing farm participation, by replacement of approx. 500 farms.

The sample of subperiod one (SP1) includes farms which have at least seven records in 1996/97-2005/06, and similarly the sample of subperiod two (SP2) which have at least seven records in 2006/07-2015/16. The sample of the total period (TP) of 1996/97-2015/16 includes those farms for which the conditions for subperiod one and two are fulfilled. The number of seven is selected to balance between the objective of having long time series and the objective of keeping a high number of farms in the samples.

We select samples for price and yield analysis trying to balance a large sample size and explanatory power (Table 1). For each product analysed, we choose two samples – one for yields and one for prices – to maximize the number of farms which provide data on the subject of interest. We ensure that only farms are selected which exceed certain minimum size[7] with regard to the production of the respective product. Due to lack of data in yields of animal production we do not provide results on animal yield risk. The sample size for prices and yields varies between 46 farms (egg price) and 2,500 farms (wheat yield) and between an average of 17.7 and 18.7 observations per farm. The observations per year vary because there are often fewer observations in the first years and the last years of the period 1996/97-2015/16 than in the rest of the period.

As an income indicator, we use the accounting profit per farm. Therefore, for the income analysis, legal persons are excluded from the sample, because they have incomparable income metrics. Part-time farmers are excluded because the agricultural income risk is not as relevant for these farms due to the small share in household income. Farms with an average income below the existence minimum of 16,980 € (Bundesministerium für Finanzen, 2015) are excluded from the sample. If farms do not reach such an average level over the period of at least 14 years, we assume that these farms have significant other sources of income and are not the focus of our study. The results are differentiated by the specialisation of farms, because specialisation has a major influence on risk exposition (e.g. European Commission, 2017a). Thus, according to EU- typology (European Commission, 2008) specialisation in crops, horticulture, dairy, other grazing livestock and pig & poultry as well as no specialisation, i.e. mixed farms, are distinguished. "Mixed" refers to farms which have several branches of production, but no branch of production predominates in economic terms. Table 2 provides an overview of sample characteristics. On average, 18.3 observations per farm are available in the entire income sample (N=1,755). The observations per year vary, because often in the first and last 1-2 years of the period 1996/97-2015/16 less observations are available than in the rest of the period. The average income is 51,043 € per farm.

Other grazing livestock farms are substantially unrepresented in our sample in comparison to the population of German farms, because a large share of the other grazing livestock farms are small and managed by part-time farmers, which are not subject of our study. The farms of our sample are spread over all German regions ('Bundesländer'). Due to the exclusion of small farms and part-time farms, farmers are under-represented in the south of Germany (Baden-Württemberg and Bavaria). Further information on the characteristics of the sample can be found in Annex 2.

[6] The farm accounts refer to the German agricultural economic year (farming year).
[7] Minimum size: wheat, winter barley, summer barley, rye, corn, rapeseed ≥ 2 ha; sugarbeet, potatoes ≥ 1 ha; head of cows, head of beef ≥ 10; head of fattened pigs, head of piglet ≥ 20; head of layer ≥ 50 (details in Annex 1)

Table 1: Summary statistics of the farm samples for price and yield risk analysis (prices deflated to 2016)

	Sample for Prices							Sample for Yields						
	Farms				Obs. per farm	Mean[1] price		Farms				Obs. per farm	Mean[1] yield	
	Total period (N)	Per year						Total period (N)	Per year					
		Mean	Min	Max					Mean	Min	Max			
Wheat	1,801	1,663	1,271	1,754	18.5	€/t	158	2,500	2,329	1,820	2,453	18.6	t/ha	7.1
Wint. barley	875	792	576	849	18.1	€/t	139	2,107	1,942	1,516	2,056	18.4	t/ha	6.4
Sum. barley	362	325	239	355	17.9	€/t	163	562	508	385	550	18.1	t/ha	5.1
Rye	411	369	266	401	17.9	€/t	135	488	440	315	473	18	t/ha	5.5
Corn	155	134	95	149	17.3	€/t	149	191	169	120	186	17.7	t/ha	8.8
Rapeseed	1,081	984	670	1,056	18.2	€/t	309	1,098	1,001	678	1,075	18.2	t/ha	3.7
Sugar beet	883	823	603	873	18.6	€/t	52	886	826	605	876	18.6	t/ha	62
Potatoes	242	221	154	241	18.2	€/t	120	244	223	155	243	18.3	t/ha	34
Milk	1,847	1,730	1,332	1,826	18.7	€/t	366			N.A.				
Beef	401	364	270	391	18.2	€/head	1,171			N.A.				
Hogs	705	649	482	698	18.4	€/head	148			N.A.				
Piglets	336	306	219	329	18.2	€/head	59			N.A.				
Eggs	46	42	29	46	18.2	€/egg	0.14			N.A.				

Notes: 1) 20 % trimmed mean. *Source:* own calculations based on FADN data

Table 2: Summary statistics of the farm sample for income risk analysis (income deflated to 2016)

	Farms					Obs. per farm	Income (€/farm)		
	Total Period (N)		Per year						
	Sample	Germany[2]	Mean	Min	Max		Mean[1]	Q1	Q3
All	1,755 (100 %)	275,000 (100 %)	1,607	1,175	1,722	18.3	51,043	32,928	74,423
Crops	453 (26 %)	83,900 (33 %)	421	294	447	18.6	66,497	40,481	94,615
Horticulture	159 (9 %)	6,400 (3 %)	146	108	159	18.3	46,954	32,040	70,543
Dairy	624 (36 %)	53,100 (21 %)	575	432	618	18.4	47,753	32,038	66,270
Other grazing livestock	75 (4 %)	60,900 (24 %)	68	49	74	18.2	40,761	27,998	55,685
Pig & Poultry	116 (7 %)	1,600 (6 %)	101	54	116	17.5	50,895	33,613	75,182
Mixed	328 (19 %)	35,300 (14 %)	296	224	319	18.0	45,137	29,194	66,440

Notes: 1) 20 % trimmed mean; Q1/Q3: 1st/3rd quartile. *Source:* own calculations based on FADN data; 2) own calculations based on Statistisches Bundesamt (2017a) (without permanent crops).

4 Results

In this section, we first display the calculated risk measures for income, prices and yields, then we present the results for the influence of farm characteristics on farm income risk, and finally describe the results of the income risk decomposition.

4.1 Risk measures

Farm income, price and yield risk are quantified by the CV to measure relative fluctuations.

4.1.1 Income risk

Table 3 shows the CV of income of six farm types: crops, horticulture, specialized dairy, other grazing livestock, pig & poultry and mixed farms. The CV on average is 49 %, but varies across farm types. The lowest CV is observed for dairy farms (43.1 %) and the highest in pig & poultry farms (69.2 %). Comparing SP1 and SP2 for all farms we observe on average an increase in the CV by 15 %-points. The increase is especially large in in dairy farms (+30 %) and crop farms (+13 %) (the biggest subsamples). Other grazing livestock and mixed farms show a smaller increase in income fluctuations, while the CV of income in pig & poultry farms remains more or less similar in the two subperiods, and decreases for horticulture farms. Despite differences in the trimmed mean, there is a big overlap of interquartile ranges. Further it is striking that the CV in TP exceeds the CV in SP1 and SP2. This is a consequence of the period-specific detrending of SP1 and SP2 which captures some risk in the subperiods.

Table 3: CV for income depending on farm type and period

		All		**Crops**		**Horticulture**		**Dairy**		**Other grazing livestock**		**Pig & Poultry**		**Mixed**	
		Ø	*Q1* *Q3*	Ø	*Q1* *Q3*	Ø	*Q1* *Q3*	Ø	*Q1* *Q3*	Ø	*Q1* *Q3*	Ø	*Q1* *Q3*	Ø	*Q1* *Q3*
TP	**1996/97-2015/16**	49.0	*35.0* *67.9*	53.8	*36.6* *74.5*	43.4	*27.8* *61.8*	43.1	*32.8* *56.3*	50.5	*35.1* *67.1*	69.2	*49.0* *92.5*	51.1	*36.3* *70.2*
SP1	**1996/97-2005/06**	39.1	*25.5* *57.4*	43.2	*27.5* *64.2*	38.5	*22.8* *58.9*	31.7	*23.0* *43.5*	41.3	*25.2* *65.0*	60.8	*44* *79.5*	43.5	*27.9* *63.1*
SP2	**2005/06-2015/16**	44.9	*30.2* *63.8*	48.9	*33.0* *67.5*	33.9	*20.0* *54.8*	41.2	*29.5* *56.9*	46.9	*33.5* *64.4*	63.2	*42.3* *94.6*	45.7	*31.3* *63.5*
p-value change SP1 vs. SP2		*		*		n.s.		*		n.s.		n.s.		n.s.	

Notes: Ø: 20 % trimmed mean; Q1: first quartile; Q3: third quartile; *(n.s): Hypotheses of SP1 and SP2 being equal (not) rejected at 5 %-level; CV = coefficient of variation. *Source:* own calculations based on FADN data.

4.1.2 Price and yield risk

While income risks increase moderately, the analysis of price risk draws a different picture. Table 4 shows the CV of prices for crops (top of the table) and animals and animal products (bottom of the table). We observe higher CVs for crop prices and lower CVs for animal and animal product prices. The lowest CV in TP is 10.2 % for milk and the highest is 27.6 % for potatoes. Further, indicated by the 25th and 75th percentile, we see that there are little differences in price risk between individual milk producers while there are big differences between potatoes farmers. If we consider changes between SP1 and SP2 we see that there is a substantial increase of price fluctuations for crops (except potatoes), with the highest increase observed for rye (+169 %) and milk (+ 111 %). For beef, fattened pig and piglet, fluctuations decreased, especially for fattening pigs (-50 %). For methodological purposes it shall be noted that the higher CV in TP in comparison to SP1 and SP2 is due to the subperiod specific trend (when analysing subperiods), which captures some risk (see above). In our analysis of price risk this effect is particularly noticeable as there are strong differences in price developments between SP1 and SP2.

Next to price risk we are analysing yield risk (Table 4). In TP the lowest risk is observed for wheat (15 %) and the highest for rapeseed (23.1 %). The variations between farms are similar across products. Considering the changes over time, we observe a slight increase in the CV for grains (except corn and wheat) and potatoes. For rapeseed we observe a decrease in yield fluctuations.

Table 4: CV for prices and yields depending on product and period

	Prices										Yields									
	TP: 1996/97-2015/16			SP1: 1996/97-2005/06			SP2: 2005/06-2015/16			p-value SP1 vs. SP2	TP: 1996/97-2015/16			SP1: 1996/97-2005/06			SP2: 2005/06-2015/16			p-value SP1 vs. SP2
	Ø	*Q1*	*Q3*	Ø	*Q1*	*Q3*	Ø	*Q1*	*Q3*		Ø	*Q1*	*Q3*	Ø	*Q1*	*Q3*	Ø	*Q1*	*Q3*	
Wheat	23.0	*20.9*	*25.3*	10.5	*8.0*	*13.5*	23.5	*20.9*	*26.2*	*	15.1	*11.4*	*19.7*	14.1	*9.8*	*19.0*	14.2	*9.9*	*19.2*	n.s.
W. barley	22.5	*20.5*	*24.7*	8.8	*6.6*	*11.9*	23.2	*21.0*	*25.6*	*	16.5	*12.4*	*20.8*	14.7	*10.0*	*19.9*	15.5	*10.5*	*20.8*	*
S. barley	23.2	*20.3*	*26.3*	11.6	*8.9*	*14.6*	24.9	*21.1*	*28.9*	*	17.9	*13.8*	*22.8*	15.8	*11.6*	*20.9*	17.1	*12.0*	*23.7*	*
Rye	25.1	*22.9*	*27.6*	9.5	*7.7*	*11.7*	25.7	*23.1*	*28.5*	*	21.9	*17.2*	*26.5*	19.7	*14.2*	*25.3*	20.7	*15.4*	*26.6*	*
Corn	26.4	*21.9*	*30.7*	18.6	*12.0*	*26.1*	26.0	*21.4*	*30.4*	*	20.0	*14.4*	*26.4*	19.1	*12.5*	*25.2*	18.7	*11.9*	*26.4*	n.s.
Rapeseed	19.0	*17.1*	*20.9*	13.5	*11.2*	*16.2*	18.1	*16.1*	*20.1*	*	23.1	*18.3*	*28.1*	23.4	*17.4*	*29.8*	20.7	*15.0*	*27.0*	*
Sugar beet	17.2	*15.3*	*19.4*	12.1	*9.4*	*14.8*	19.8	*17.0*	*23.1*	*	16.1	*12.2*	*20.2*	14.1	*10.5*	*18.2*	15.7	*11.6*	*20.5*	*
Potatoes	27.6	*21.1*	*34.7*	23.5	*15.7*	*32.4*	24.0	*17.9*	*32.3*	n.s.	21.7	*16.8*	*27.2*	20.0	*14.7*	*26.3*	20.0	*13.9*	*27.6*	n.s.
Milk	10.2	*9.5*	*10.9*	6.2	*5.4*	*7.0*	13.1	*12.0*	*14.3*	*	N.A.									
Beef	13.0	*9.9*	*16.5*	12.0	*9.4*	*15.4*	10.2	*6.9*	*14.8*	*	N.A.									
Hogs	12.7	*11.7*	*13.9*	15.9	*14.6*	*17.1*	7.9	*7.2*	*8.9*	*	N.A.									
Piglets	17.8	*15.4*	*20.7*	19.3	*17.2*	*22.1*	13.6	*11*	*17.1*	*	N.A.									
Eggs	12.3	*8.0*	*18.6*	8.6	*4.9*	*16.4*	9.4	*5.4*	*14.8*	n.s.	N.A.									

Notes: Ø: 20 % trimmed mean; Q1: first quartile; Q3: third quartile; *(n.s): Hypotheses of SP1 and SP2 being equal (not) rejected at 5 %-level; CV = coefficient of variation. *Source:* own calculations based on FADN data.

In summary we find that the level of risk faced is heterogeneous across farms. Some variation can be explained by farm types and subperiods. Comparing income risk in SP1 and SP2 we observe an increasing tendency in income risk (particularly for crop and dairy farms). Income risk of dairy farms and milk price risk increased from a low level of risk to a still below-average level of risk. It is striking that level of CV for income is substantially higher than for prices and yields.

For price risk we conclude that differences between products exist, especially between crop (high) and livestock (low) products. Differences also occur between SP1 and SP2. Milk price risk is one of the lowest in all periods. We conclude for yield risk that it is slightly increasing for most crops.

4.2 Influence of farm characteristics

Table 5 shows the regression results for the influence of farm characteristics on the farm income risk. With the increase of return on sales by 1 percent point, i.e.1 percentage point, the CV decreases by 1.03 percentage points. As expected, this effect is positive. To assess relevance of this factor, we have standardised the coefficients by multiplying them with the standard deviation[8] of the explanatory variables. The standardized coefficient shows that the increase of the return on sales by one standard deviation leads to a reduction of the CV by 13.10 percentage points. Compared to the other factors the return on sales has a great effect on farm income risk and therefore is one of the most relevant.

As expected, the external production factors labour and capital make a positive contribution to the farm income risk. It is striking, however, that the factor rentend land has no relevant effect (stand. coeff. 0.20).

[8] For this purpose, we use the standard deviation of the outlier-free observations of the explanatory variables.

While the degree of specialisation for the levels “branches of agriculture” (stand. coeff. 1.55) and the ”variety of crops for all farms” (stand. coeff. 0.86) show only relatively small positive effects on the CV, the effect of crop variety for arable farms is greater (stand. coeff. 0.86 + 3.04 = 3.90). At the level of “agricultural production and non-agricultural” production, however, the effect of specialisation is close to zero with a slight negative tendency.

Increasing farm size has a slightly negative effect on farm income risk. This result is in line with our expectations. If the size increases by one standard deviation, the farm risk is reduced by 0.64 percent points.

It is also striking that differences between farm types remain after controlling for numerous farm characteristics. However, the differences between farm types change. Due to controlling for farm characteristics the difference between crop and horticulture farms decreased, while the difference between crop and dairy farms slightly increased. (cf. chapter 4.1.1: there, horticulture is 10.4 percent points lower than crops, dairy 10.7, other grazing livestock -3.3, pig & poultry 15.4, mixed -2.7). The difference between crop and pig & poultry farms slightly decreases. We suppose that the differences between farm types –that exist despite controlling for numerous farm characteristics– are mostly due to differences in the output structure and the respective price and yield risk of the key products produced by the farms.

Table 5: Regression results for effects of farm characteristics on farm income risks during the period 1996/97-2015/16

Factors			**Hypothesis**	**Observed effect**			
		Unit	**Sign of coeff.**	**Coeff.**	**Standardised coeff.[1]**	**p-value**	**Std. err.**
Return on sales	Market return to sales revenue ratio	%	-	-1.03	-13.10	***	0.04
External production factors	External workforce ratio	%	+	0.05	0.93	*	0.03
	Leased land ratio		+	-0.01	-0.20		0.01
	Debt ratio		+	0.06	1.23	***	0.02
Size	Standard gross margin	10.000 €	-	-0.09	-0.64	*	0.05
Degree of speciali-sation	Agriculture and non-agriculture	Herfindahl-index	+	-6.95	-0.62		4.83
	Branches of agriculture		+	7.67	1.55	*	3.81
	Varitiy of crops		+	3.55	0.86	*	2.15
	for crop farms plus[2]		+	22.41	3.04	***	7.36
Farm type (Type of speciali-sation)	Crop	“Dummies” (in comparison to crop farms)		*Reference*			
	Horticulture		o	-14.74		***	3.83
	Dairy		o	-4.00			3.16
	Other grazing livestock		o	-4.91			3.50
	Pig & Poultry		o	7.78		*	3.77
	Mixed		o	-1.84			3.26
R-squared				0.27			
AIC				1428			
BIC				1637			

Notes: 1) Coefficient multiplied with the (robust) standard deviation of explanatory variables; 2) The effect has to be added to the “varity of crop farms” to get the effect of crop variety for crop farms; *: <= 0.1; ** <= 0.05; *** <= 0.01; in addition, we controlled for direct payments, region, age of the farm manager, unemployment rate and GDP per capita. *Source:* own calculations based on FADN data.

Finally, our explanatory variables, including the control variables for region, age and socioeconomics of the region, explain 27 % of the income variance. Given the numerous factors that influence the fluctuation of farm income beyond our explanatory variables, includingfarm specific losses (e.g. due to local weather events or accidents), farmers' skills and personality (e.g. risk attitude, because risk averse farmers might choose activities which are less risky), (dis)investment activities and the availability of risk management instruments (e.g. non-agricultural income, private assets, insurance), the explanatory power of the model appears to unexpectedly good.

4.3 Decomposition of income variation into revenue and cost components

Income risk variation is decomposed into its components sales revenue, other revenue, material costs and other costs. The results of the income variance decomposition (Table 6) show that the contribution of sales revenue is higher than that of other direct effects and thus the most important component in the period 1996/97-2015/16 (109 % for all farms). The lowest contribution of sales revenue is observed for dairy farms (99 %), the highest for pig & poultry farms (175 %). Importance of other revenue, material costs and other costs is generally lower and depends on the farm type. Outstanding are the high contributions of the direct effect of other costs in horticulture (e.g. labour costs) and the direct variance effect of material costs in pig & poultry farms (e.g. feed).

Table 6: Contribution of income components to the variance of income depending on farm type (in %)

	Direct effect				Interaction effect					
	Sales revenue	Other revenue	Material cost	Other cost	Sales revenue with material cost	Sales revenue with other cost	Sales revenue with other revenue	Material cost with other revenue	Material cost with other cost	Other revenue with other cost
All	109↑*	38↘*	28↗*	36↘*	-63↓*	-34→	2↗*	-6↘*	11↗*	-22↗*
Crops	105↑*	36↓*	16↗*	32↘*	-43↘*	-31↗*	2↗	-5↘	7↘	-20↗*
Horticulture	138↗	30↘*	43↗	74↓*	-94↘	-77→	5→	-5↗	20↗	-35↑*
Dairy	99↑*	39↓*	23↗	41↘*	-54↓*	-33↘	2↗*	-5↘*	12↗*	-24↗*
Other grazing livestock	110↗	63↘*	44↗	32↗	-79↘	-23↘	-28↑*	-6↘	13→	-25↘
Pig & Poultry	175↗	30↗*	79↑*	17↗	-163↓*	-31↗	2↘	-15↘*	18↗	-12→
Mixed	134↑*	43↘*	47↗*	32↘	-109↓*	-37↘	6↗	-14↘	17↗	-20↗*

Notes: Arrows indicate change between SP1 (1996/97-2005/06) and SP2 (2006/07-2015/16); vertical arrow: > 30 percent-points change; sloping arrow: 30 to 0 percent points change; horizontal arrow: 0 percent points change; *: Null hypothesis of trimmed mean for SP1 and SP2 being equal is rejected at 5 %-level. *Source:* own calculations based on FADN data.

For every farm type in all periods (except for crop and dairy farms in SP1) the contribution of sales revenue fluctuations to income variance is above 100 %. The occurrence of values larger than 100 % for the contribution of one direct effect (or even for the sum of all direct effects) may be surprising at first glance. The reason is that the sum of all direct and interaction effects is defined to be 100 %[9]. Interaction effects, which are based on the correlation between two components, can reduce overall income risk (i.e. have a 'negative' contribution to overall variance), thus implying that some components' contribution is above 100 %. For instance, the direct effect of sales revenue variation on income variation (109 %) is reduced by its interaction with material cost (-63 %), which means that in years with low (high) sales revenue also low (high) costs can be expected. In TP the most negative interaction (highest variance reduction) is observed for material costs in pig & poultry farms (-163 %). Also, interactions between sales

[9] While the sum is 100 % for each individual farm, for aggregated group data the sum sometimes differs from 100 % because the aggregation is based on the trimmed mean rather than the arithmetic mean. The values were therefore scaled to sum up to exactly 100%.

revenue and material costs in horticulture, other grazing livestock, and mixed farms are high (-109 to -79 %), as well as the interaction between sales revenue and other costs in horticulture farms (-77 %). A positive contribution of the interaction term to income variance is rarely observed (highest value: +20 % for material costs and other costs in horticulture). It is striking that interaction terms for crop and dairy farms are rather low compared to other farm types.

Looking at changes between SP1 (1996/97-2005/06) and SP2 (2006/07-2015/16), indicated by arrows in table 6, we see that the importance of sales revenue fluctuations for income risk increases in the second period, the importance of material costs decreases (except in pig & poultry farms) and the interaction effect between sales revenue and material costs becomes stronger (more negative). A hypothesis test shows that the difference between the trimmed means of SP1 and SP2 can also be observed for most farm types and risk components in the population of German farms.

5 Discussion and Conclusion

A comprehensive whole farm risk analysis is the basis for effective risk management of all actors in agriculture. The existing literature is often limited to a single risk component or product group for a limited period of time. This study aims to fill this gap and provides the most comprehensive and up-to date analyses of risk exposition of German farms available, covering a wide range of products, farm types and income risk components, based on long time-series (1996/97-2015/16) data for a large sample of farms. We also use the sample to analyse the effect of farm characteristics on farm income risk. To our knowledge, specifically the effect of the return on sales and the influence of various external production factors has not yet been empirically investigated in the literature. Further, the change in risk exposure before and after 2007 is presented.

Our results show that the risk exposure of German farmers is very heterogeneous (corroborating the findings of European Commission, 2017a, Kimura, Antón and LeThi, 2010 and Severini, Biagini and Finger, 2018). This is due to three reasons. First, the composition of various risk components varies and thus causes heterogeneity. Second, differences in farm characteristics like return on sales cause heterogeneity. Finally, differences are caused by characteristics that are difficult to detect, such as farm specific losses, the farmers' skills and personality (e.g. risk attitude, because risk averse farmers, (dis)investment activities and the availability of risk management instruments. Accordingly, risk management is a complex task that needs to be carried out on an individual farm basis.

By using the CV (for quantifying the extent of relative variations) our risk measurement shows that the perceived levels of risk (in public, in the media) do not reflect the level of risk present in the data. The objective measurement of the risk helps to assess risk realistically. Our analysis reveals an overall increase in income risk; however, the development of risk is ambiguous depending on the type of farm. The substantial increase in price risk from 2007 onwards does not increase farm income risk to the same extent. Despite the increase in the income risk for dairy farms, the level of risk in dairy farming is comparatively low even in the more recent time period analysed. In contrast, the income risk for pig & poultry farms is the highest. This is a result also established by European Commission (2017a) for other EU member states. The widespread perception of an economic crises triggered by price fluctuations in dairy farming despite farm income risk still being lower than that of most other farm types highlights that the change in risk exposure (i.e., the observed increase in price and farm income risk dairy farming after 2007) can be more relevant than the absolute level of risk. In such situations characterized by changes in risk exposure there is particular potential for farmers to learn from risk management strategies implemented in other sectors that have been exposed to the higher level of risk before.

Considering farm characteristics, the return on sales, the use of external factors and the degree of specialisation are important to explain farm income risk. The quantitative results highlight especially the relevance of the return on sales, which confirms the hypothesis of Vrolijk *et al.* (2009) and Mußhoff and Hirschauer (2016). On the one hand the high relevance of return on sales indicates that increasing the profit per output is an effective risk management instrument to reduce income fluctuation. In this respect, the substitution of external inputs by internal inputs could be a management option to increase the profit per output (e.g. forage production instead of buying in; young animal breeding instead of buying in) and reduce the exposure to e.g. input price risk. Even if these measures are likely to reduce the total income, they also tend to reduce risk. In addition, an increase in efficiency also generally offers a possibility to increase the return on sales e.g. by increasing the sales price or reducing input costs. Furthermore, growth could also increase the return on sales if farms can benefit from economies of scale. On the other hand, the high relevance of the return on sales implies that decreasing profit per unit of output due to structural change will increase farm income risk considerably. From this point of view, structural change has an increasing effect on income risk. In addition, the analysis of farm characteristics shows, farm income risk differs substantially between farm types, although we controlled for various risk factors. This observation reveals that a substantial part of the risk is attributable to the product-specific production risks and market price risks.

Our income risk decomposition shows that farm income risk is primarily caused by fluctuations in sales revenue, instead of other revenue or cost components. The significance of sales revenue increased after 2007, especially for dairy farms and crop farms. This development is primarily attributable to the significantly increasing price risk in these two farm types. In addition to fluctuations in sales revenue, fluctuations in costs, in particular material cost, also contribute to the risk. Finally, our study our study shows that the income risk is substantially reduced by the correlation between risk components.

Several policy implications are derived from the risk quantification. First, we conclude that due to the heterogeneity of farms, efficient risk management strategies must be designed and implemented at the farm-individual level. Next, due to the complexity of the agricultural income risk, i.e. numerous individual characteristics of the risk components, their interactions as well as biases present in the perception and management of risks (Kahneman, 2011), it can be assumed that appropriate risk management know-how is required for the perception of risks, i.e. probabilities and damage potentials, as well as for the implementation of efficient risk management measures. Education and consultancy are therefore particularly suitable instruments for promoting risk management. In addition, it is important to use and promote the exchange between the sectors in order to pass on experience in dealing with certain risks.

When making conclusions from our study one has to have in mind that we illustrate the realized (observed) risk on the farm-level. The analysis of observed variability, although we controlled for farm characteristics, is still subject to the usual caveat that some farmers' decisions and strategies (e.g. insurance, financial reserves, private assets, adopted production methods, price hedging) are already embedded in our results (Kimura, Antón and LeThi, 2010). Realised incomes, prices and yields are the result of many factors, such as farm specific (e.g. risk attitude) or external factors (e.g. availability the of insurance, marketing contracts, contracts for price hedging or non-agricultural income in the region as well as regional weather conditions).

Although our database allows for a comprehensive farm risk analysis it has some shortcomings. First, valid household income data are not included in FADN, although this is often important for decisions in agricultural risk management. We have tried to minimise the impact of off-farm income by analysing the income of only full-time farms with a minimum income-level. At the same time, the exclusion of part-time farms leads to an underrepresentation of agricultural holdings in southern Germany. Second, the FADN underrepresents complex corporate structures, i.e. economically linked but legally separate entities. This problem primarily affects larger farms and pig & poultry farms (Forstner and Zavyalova, 2017). Next, legal persons are excluded from income analysis. In summary, our income analysis thus focuses on the "classical" full-time family farm. For the interpretation of the results on income risk, it thus needs to be taken into account that in regions with a high share of part-time-farms (e.g. Southern Germany) or legal persons (Eastern Germany) a significant part of agriculture is not represented by the sample. Finally, although farm data of 20 years is much in terms of farm studies, for probability theory 20 years is not much. Especially observations of extreme events in the sampling period could be biased, which does not allow to transfer our results to other (future) periods.

Future research should empirically investigate the expected value formation in agriculture. Further methods of expectation value formation could be used to describe the absolute level of risk in more detail. Accounting for the role of autocorrelation and cycles in expectation formation and measurement of risk exposure in short time series remains a challenge in many empirical settings and merits further research.

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Annex

Annex 1: Minimum farm size and deleted observations

	Minimum size			Number deleted	
	Measure		Condition	Prices	Yields
Wheat	ha	>=	2	41	211
Winter barley	ha	>=	2	30	203
Summer barley	ha	>=	2	20	109
Rye	ha	>=	2	27	51
Corn	ha	>=	2	11	48
Rapeseed	ha	>=	2	94	104
Sugar beet	ha	>=	1	29	27
Potato	ha	>=	1	81	175
Milk	head average livestock	>=	10	61	N.A.
Beef	head average livestock	>=	10	406	N.A.
Fattened pig	head average livestock	>=	20	338	N.A.
Piglet	head average livestock	>=	20	64	N.A.
Egg	head average livestock	>=	50	51	N.A.

Source: own calculations

Annex 2: Further description of farm data

Description of the income sample (income deflated to 2016)

	Total number of farms in Germany 2016[2] in 1,000 (in %)	Sample[3]				
		N (in %)		Mean[1]	Q1	Q3
Crops	83.9 (33 %)	453 (26 %)	UAA	131	69	218
			WU	1.7	1.3	2.4
			Income	66,497	40,481	94,615
Horticulture	6.4 (3 %)	159 (9 %)	UAA	1	1	3
			WU	4.0	2.6	6.0
			Income	46,954	32,040	70,543
Dairy	53.1 (21 %)	624 (36 %)	UAA	54	33	81
			WU	1.7	1.4	2.0
			Income	47,753	32,038	66,270
Other grazing livestock	60.9 (24 %)	75 (4 %)	UAA	84	50	120
			WU	1.8	1.4	2.3
			Income	40,761	27,998	55,685
Pig & Poultry	16 (6 %)	116 (7 %)	UAA	46	31	64
			WU	1.7	1.4	2.1
			Income	50,895	33,613	75,182
Mixed	35.3 (14 %)	328 (19 %)	UAA	72	47	102
			WU	1.8	1.4	2.2
			Income	45,137	29,194	66,440

Notes: 1) 20 % trimmed mean; Q1/Q3: 1st/3rd quartile; UAA: utilized agricultural area; WU: worker unit. *Source:* own calculations based on 2) Statistisches Bundesamt (2017a) (without permanent crops) and 3) FADN data.

Description of the price and yield sample (prices deflated to 2016)

		Sample for prices				Sample for yields			
		N	Mean*	Q1	Q3	N	Mean*	Q1	Q3
Wheat	ha/farm	1,801	26.8	11.8	51.0	2,500	19.8	9.5	36.8
	% of UAA		28.1	19.6	36.7		26.1	17.8	34.3
	Price[1], Yield[2]		158.1	149.7	166.9		7.1	6.3	7.9
Winter barley	ha/farm	875	25.0	9.8	55.4	2,107	12.4	6.9	20.5
	% of UAA		15.6	11.4	20.2		16.5	11.2	22.5
	Price[1], Yield[2]		139.3	131.8	147.7		6.4	5.7	7.0
Summer barley	ha/farm	362	16.0	8.0	30.0	562	11.8	6.7	19.6
	% of UAA		17.1	11.8	23.1		16.3	11.1	22.4
	Price[1], Yield[2]		163.3	154.1	172.5		5.1	4.6	5.6
Rye	ha/farm	411	37.0	10.9	91.6	488	30.4	9.3	72.9
	% of UAA		15.8	10.8	22.1		15.4	10.5	21.6
	Price[1], Yield[2]		134.6	127.0	143.7		5.5	4.5	6.5
Corn	ha/farm	155	11.8	6.7	17.9	191	12.7	7.9	18.7
	% of UAA		19.7	11.8	27.9		21.9	13.7	30.5
	Price[1], Yield[2]		149.1	133.7	164.0		8.8	8.0	9.7
Rapeseed	ha/farm	1,081	26.2	9.7	59.8	1,098	25.8	9.7	57.3
	% of UAA		15.2	11.4	19.3		15.2	11.3	19.4
	Price[1], Yield[2]		308.6	297.4	319.1		3.7	3.2	4.0
Sugar beet	ha/farm	883	9.8	4.9	17.9	886	9.8	4.9	17.8
	% of UAA		10.1	5.0	17.0		10.1	5.0	17.0
	Price[1], Yield[2]		52.1	48.9	55.8		62.2	56.6	68.1
Potato	ha/farm	242	14.5	5.6	30.2	244	14.6	5.6	30.3
	% of UAA		15.2	6.3	26.9		15.1	6.2	26.8
	Price[1], Yield[2]		120.2	81.1	184.6		34.2	28.4	40.1
Milk	Head of cows/farm	1,847	48	29	74	N.A.			
	Price in €/t		366	356	375				
Beef	Head bulls/farm	401	38	22	61	N.A.			
	Price in €/head		1,171	1,014	1,317				
Fattened pig	Head of fattened pigs/farm	705	293	150	467	N.A.			
	Price in €/head		147.7	143.6	152.0				
Piglet	Head of piglet/farm	336	808	458	1,267	N.A.			
	Price in €/head		59.0	55.2	62.6				
Egg	Head of layer/farm	46	1,311	262	3,638	N.A.			
	Price in €/egg		0.14	0.12	0.16				

Notes: 1) 20 % trimmed mean; P25/P75: 25th/75th percentile; 1) in €/ton; 2) in tons/ha; UAA: utilized agricultural area. *Source:* own calculations based on FADN data