Effects of production diversification on net farm income: Evidence from Kansas

Priyanka Sharma, Aleksan Shanoyan, Becatien Yao

Department of Agricultural Economics, Kansas State University

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Abstract

This study examines the relationship between crop diversification, and farm financial resilience through mixed-effects modeling. Analyzing data from 232 balanced farms in Kansas across numerous counties, our results suggest potential relationships between farm income and variables such as crop diversification, farm size, and debt-to-asset ratios. The study also considers the impact of environmental shock i.e. drought severity. Our findings, while indicative, point towards more nuanced strategies that could be beneficial in supporting farm financial sustainability and economic viability.

1 INTRODUCTION

Agricultural producers face significant revenue risks due to external factors such as adverse weather, crop pests or diseases, and market volatility. While conventional risk management techniques can manage specific risks, they lack the capacity to mitigate the impacts of unpredictable events. As a result, a system resilience approach has emerged as a potential complement to traditional risk management options. . Considering farms as socio-ecological systems, system resilience methods can help farmers to prepare for unexpected shocks (Lin 2011). Therefore, system resilience has started to find applications in production agriculture (Hammond, Berardi, and Green 2013). Recognizing this alternative, production diversification has emerged as an effective strategy that stabilizes expected returns in such environments (McNamara and Weiss 2005; Amin Mugera et al. 2016; Lindbloom et al. 2022)

As per the literature on production diversification, there are multiple agronomic and environmental factors that play an important role in the diversification decisions. Beyond these factors, diversification is increasingly acknowledged as an important risk management tool. (Tack and Yu 2021) contend that production diversification is a function of the farmer’s risk preference in conjunction with stochastic joint distribution of output prices and production shocks. Various studies by (Di Falco and Chavas 2009; Baumgärtner and Quaas 2010; Chavas and Di Falco 2012; Bezabih and Sarr 2012; Kandulu et al. 2012;

Rao 2019; Ouattara et al. 2019) show that *ex ante* risk and risk attitudes are key drivers of crop diversification. In summary, the literature indicates a relationship between risk exposure and production diversification i.e. the effects of risks on the choice of production.

A substantial body of research literature has explored the benefits of diversification, particularly in stabilizing crop yield and supporting food security under stressors such as extreme weather, abiotic stress, and market fluctuations. Various studies indicate that strategies like crop diversity and rotation play a crucial role in long-term yield and supply stability(Lin 2011; Harvey et al. 2014; Hendricks, Smith, and Sumner 2014; Gaudin et al. 2015; Renard and Tilman 2019; Degani et al. 2019; Dardonville et al. 2020; Bowles et al. 2020; Harkness et al. 2021; Pates and Hendricks 2021; Ebel et al. 2022)

Theories such as biodiversity insurance hypothesis (Yachi and Loreau 1999) and the agricultural insurance hypothesis further suggest that crop diversification acts as a natural insurance against crop loss by stabilizing productivity (Tilman, Reich, and Knops 2006; Proulx et al. 2010). Notably, a recent study highlighted the role of farm diversification in aiding small farmers during COVID-19 lockdowns (Benedek et al. 2021). However, the literature focusing on the direct effects of on-farm production diversification on farm financial resilience is still limited.

A recent study by (Lindbloom et al. 2022) used data from Kansas Farm Management Association (KFMA) to assess the impact of diversification on farm resilience, employing a resilience triangle methodology. This method involves a graphical analysis of resilience over time, focusing on the extent and duration of a system's disruption. The study found that diversifying crop acreage influences resilience non-linearly, being effective only up to a certain diversification threshold. However, a notable limitation of this approach is its inability to capture the higher-order moments to understand multifaceted aspects of resilience, especially under complex and stochastic agricultural risks.

To address this, we are examining farm profit maximization by considering net farm income generated from a diversified portfolio of crops and mixed(crop,livestock) income as another production choice, and then adopting the concept of a moment-based approach to understand its impact. Therefore, the objective is to quantify the impact of production diversification on the mean, variance, and higher-order moments of the net farm income distribution, which collectively reflect financial resilience. This concept is moving beyond the area of the triangle method to more accurately identify and aggregate farm-level resilience.

Our objective, therefore, is to empirically estimate the impact of production diversification on net farm income in Kansas using a panel dataset from the Kansas Farm Management Association (KFMA), a state with significant agricultural output and variability, as an empirical setting. Our analysis seeks to understand how multiple types of crop income can compensate for financial losses stemming from sudden loss of income during shock. Overall, the study aims to inform policy and practical decision-making in agricultural management, offering valuable guidelines for farmers, policymakers, and stakeholders in agricultural economics in Kansas and similar agricultural regions.

2 DATA DESCRIPTIVES

Analyzing the impact of production diversification on farm financial performance requires long-term farm-level data. However, datasets like the US Census of Agriculture do not provide the required farm-level details to understand the dynamic adjustments of farm operations. This study leverages a unique dataset from the Kansas Farm Management Association (KFMA) survey, wherein farmers provide detailed data on farm production and finances explicitly for research purposes. The balanced panel data spans 2002-2022 (21 years) and includes 232 Kansas farms, offering a rich longitudinal perspective on diversification strategies and financial performance. As shown in figure 3, mean inflation adjusted farm income vary both spatially and temporally due to localized growing conditions, market conditions and production technology.

The sample comprises 231 crop-only or mixed (crop and livestock) farms and one livestock-only farm, captured in the farm type categorical variable. In 2002, there were 45 crop-only and 186 mixed farms, while in 2022, the numbers shifted to 90 crop-only and 141 mixed farms, indicating a trend towards more crop-only operations over time. The average crop acreage remained relatively stable, with crop-only farms having slightly higher acreage than mixed farms in both years. The debt-asset ratio decreased from 2002 to 2022, with crop-only farms exhibiting a lower ratio than mixed farms in both years, indicating improved financial positions. Due to the lack of data on livestock-only farms, the analysis focuses primarily on crop diversification and its impact on farm financial resilience

The inverse hyperbolic sine transformation is applied to net farm income and other financial metrics to manage negative and zero values effectively. Additionally, all financial measures are adjusted for inflation using the Consumer Price Index (CPI). The interpretation of the coefficients would be similar to the use of log of the dependent (Bellemare and Wichman 2020). The density plots in Figure 1 provide insights into the distribution of adjusted mean farm income before and after 2012, a severe drought year taken to understand the pre and post-shock variation in mean farm income.

The density plot categorized by the number of crops grown in figure 1 shows a clear pattern: farms with a greater number of crops tend to have higher levels of inflation-adjusted mean farm income without government support or insurance. The peak of the distribution shifts progressively to the right as the number of crops increases, with farms growing six or more crops exhibiting the highest income levels. The density plots in Figure 4 provide insights into the distribution of adjusted mean farm income before and after 2012. 2012 is a taken as severe drought year to understand the pre and post shock variation in mean farm income.. It is evident that the distributions of mean farm income without government payments, insurance premiums, and claims exhibit a rightward shift even after 2012. Furthermore, These findings highlight the potential economic benefits of crop diversification in enhancing farm financial resilience.

2. 1 Construction of Diversification Index using Herfindahl-Hirschman Index (HHI)

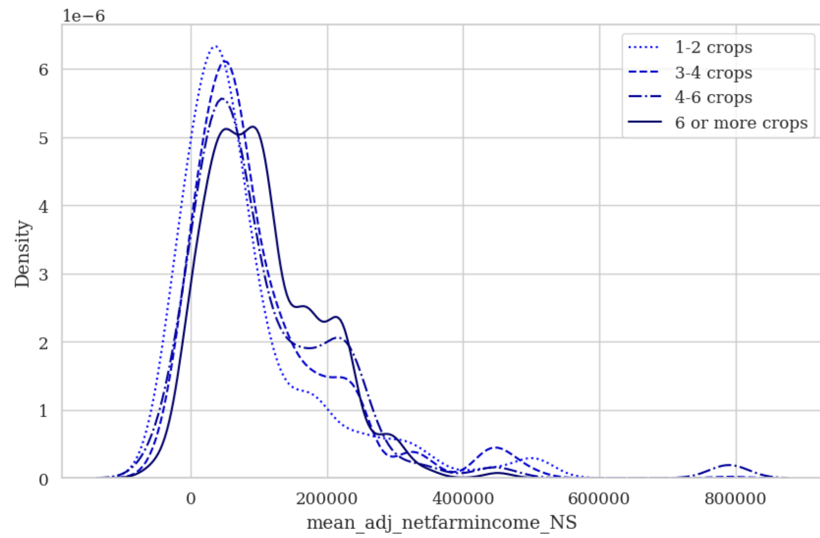
Crop diversification characteristics were captured using multiple variables. First, the number of crops grown on each farm out of 32 crops in the region was counted. Second, crops contributing at least 10% of acreage or income were identified. To quantify the overall diversification level, the Simpson's Index of Diversity (SID) was calculated based on acreage and income shares. The SID measures how land is allocated among various crops, computed as $\text{Index} = 1 - \sum CropShare^2_{\frac{\text{income}}{\text{acreage}}}$. The crop acreage shares for each crop type - wheat, corn, grain sorghum, soybeans, sugar beets, alfalfa hay, silage, other grain, other hay, other cash crops are computed by dividing the acreage dedicated to each crop by the total crop acres. These indices range from 0 to 1, with higher values indicating greater diversification. The summary statistics Table 1 shows mean, and standard deviation of key farm variables, financial variables and diversification variables.

Table 1 - Comparative Descriptive Statistics of Farm Operations by Type and Year: 2002 vs. 2022

Variable	Crop-only (2002)	Mixed (2002)	Crop-only (2022)	Mixed (2022)
	(N=45)	(N=186)	(N=90)	(N=141)
Age and Education				
Age	48.93 (10.57)	49.55 (9.04)	68.98 (9.13)	66.74 (8.91)
Education	242.29 (583.40)	348.97 (1078.37)	193.33 (1411.46)	237.79 (1967.47)
Farm Characteristics				
Crop Acres	1433.78 (904.51)	1189.31 (857.91)	1424.40 (1034.33)	1502.71 (1291.58)
Debt-Asset Ratio at End of Year	0.42 (0.47)	0.38 (0.28)	0.09 (0.14)	0.16 (0.14)
Adjusted Financials				
Value of Farm Production ($k)	327.77 (269.55)	389.83 (365.64)	737.85 (652.89)	941.04 (899.31)
Net Farm Income ($k)	49.39 (72.76)	49.29 (109.43)	176.80 (225.87)	184.42 (223.97)
Government Payments ($k)	22.86 (19.64)	27.08 (19.68)	13.81 (27.16)	14.81 (33.24)
Crop Insurance Income ($k)	27.46 (40.35)	24.82 (41.36)	98.88 (135.26)	102.19 (227.32)
Crop Insurance Expense ($k)	9.84 (12.79)	5.49 (7.55)	26.08 (26.79)	23.92 (26.43)
Farm Income per Acre	33.02 (53.58)	49.68 (155.41)	111.98 (114.17)	141.95 (202.28)
Farm Income no support per Acre	4.20 (60.91)	0.65 (148.62)	51.94 (150.77)	94.13 (219.08)
Diversification Characteristics				
Crop Count Above 0 acres	3.73 (1.67)	5.38 (2.11)	3.11 (1.28)	5.50 (2.51)
Crop Count by 10% Income	2.71 (0.87)	3.05 (0.96)	2.37 (0.76)	2.62 (0.84)
Crop Count by 10% Acreage	2.84 (1.00)	2.94 (0.86)	2.46 (0.74)	2.94 (0.90)
Crop Acreage Diversity	0.57 (0.17)	0.65 (0.13)	0.53 (0.17)	0.64 (0.16)
Crop Income Diversity	0.57 (0.17)	0.64 (0.15)	0.50 (0.19)	0.58 (0.18)

N- number of farms

Figure 1: Density Distribution of Adjusted Net Farm Income Across Crop Count Categories



We also used the Drought Severity and Coverage Index (DSCI) , which is an experimental metric used by the U.S. Drought Monitor to quantify the overall drought conditions within a given area. It combines information about the severity and spatial extent of drought into a single numerical value. The DSCI ranges from 0 to 500, with 0 indicating that none of the area is abnormally dry or in drought conditions, and 500 representing an exceptional drought (D4 level) across the entire area. The index is calculated by assigning numerical values to the different drought categories (D0-D4) and then weighting them by the proportion of the area affected by each category. (https://droughtmonitor.unl.edu/)

3 EMPIRICAL STRATEGY

To empirically investigate the impact of crop diversification on farm financial resilience, we employ a moment-based approach(Tack, Coble, and Barnett 2018) that models the entire distribution of net farm income. This strategy allows us to quantify the effects of diversification on not only the mean income level but also higher-order moments variance and skewness, which collectively capture different aspects of financial resilience. The model consists of two equations. First, we regress the farmincome measure $F_{it,}$ where mean of the adjusted net farm income is a function of crop diversity and other covariates for county i and year t. Controls X_{it} are total acerage , debt to asset ratio at the beginning of the year, total farm asset at thebeginning of the year, government payments, insurance premium and claim, This study investigates the impact of crop diversification on farm financial resilience using a mixedeffects modeling framework. This approach is particularly suitable for data with hierarchical structures, common in agricultural economics where data points are nested within larger groups such as counties or regions. We estimate the effects of diversification on farm income through the following mixed-effects model:

$$E[Yit|Xit,Zit,\alpha i,\psi c] = Xit\beta + Zit\gamma + \alpha i + \psi c \quad (1)$$

where:

- Y_{it} is the adjusted net farm income for farm *i* in county *c* at time *t*, transformed using the inverse hyperbolic sine.
- X_{it} represents control variables crop acres and ‘debt asset ratio‘.
- Z_{it} includes the crop diversification index, ‘crop diversity index‘, our primary variable of interest.
- α_i captures farm-specific random effects.
- ψ_c includes county-specific random effects.

To explore the impact of diversification on the variability of farm income, we use the following variance model:

$$Var[Yit|Xit,Zit,\alpha i,\psi c] = Xit\delta + Zit\theta + \alpha i + \psi c \quad (2)$$

where δ and θ are coefficients capturing the influence of control variables and crop diversification on income variance, respectively. Both the mean and variance models are estimated using maximum likelihood estimation (MLE). This method efficiently handles the complex variance structure that is typical of hierarchical agricultural data, enabling robust estimation of both fixed and random effects. This methodology facilitates a detailed examination of how diversification influences not only the mean but also the variation in farm income, thus providing a comprehensive view of its impact on financial resilience.

4 RESULTS

The regression results explains the impact of various factors on adjusted net farm income, highlighting significant economic insights for agricultural practices. The negative coefficient associated with the Drought Severity and Coverage Index (DSCI) confirms that increased drought severity significantly reduces farm income, emphasizing the critical need for effective drought management strategies. This finding supports the implementation of agricultural policies focused on enhancing drought resilience through advanced forecasting and sustainable water management practices.

Additionally, the analysis shows a positive correlation between crop acres and net farm income, suggesting that larger farms benefit from economies of scale, thereby boosting profitability. However, a high debt asset ratio is strongly linked to lower farm income, indicating the financial vulnerabilities associated with substantial farm debts. This underscores the importance of financial advisement and support structures to aid farmers in managing debt efficiently.

The positive effect of government payments on farm income reinforces the role of subsidies or support payments in stabilizing farm revenues, thus justifying the continuation or expansion of these programs. Conversely, the negative impact of insurance expenses highlights the cost burden on farmers, which could potentially negate the financial benefits of such schemes.

Significant findings regarding farm size categories reveal that larger farms generally report higher incomes, advocating for policies that support scalability and efficiency in farm operations. Moreover, the interaction between crop acreage diversity and DSCI suggests that diversification in cropping can mitigate the adverse effects of drought on income. This promotes agricultural diversification as a strategic approach to enhance resilience against environmental challenges.

These insights are pivotal for policymakers, agricultural stakeholders, and farmers, directing the focus towards tailored strategies that enhance economic stability, promote sustainability, and foster resilience in the agricultural sector. Such strategic implications are crucial for the development of informed agricultural policies and practices that safeguard against economic uncertainties and climatic risks.

Table 2: Mixed-Effects Maximum Likelihood Regression Results

Variable	Coefficient	Std. Error	z-value	P-value
DSCI	−0.0001753***	0.0000734	-2.39	0.017
Crop Acres	0.0004139**	0.0001571	2.63	0.008
Debt Asset Ratio	−2.413527***	0.5108759	-4.72	< 0.001
Adj. Govt Payments Lag	0.3964905***	0.0490317	8.09	< 0.001
Adj. Insurance Income Lag	0.0212172	0.0243609	0.87	0.384
Adj. Insurance Expense Lag	−0.104977**	0.0451395	-2.33	0.020
Farm Size: 500 to 1000	2.129803***	0.3908058	5.45	< 0.001
Farm Size: 1000 or more	3.099635***	0.4546721	6.82	< 0.001
Interaction Crop Acreage Diversity & DSCI	0.0002517*	0.0001151	2.19	0.029

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Random-effects parameters estimated with variances for CountyNum and residual variance provided in text.

5 CONCLUSIONS

The findings from this study contribute preliminary insights into the complex dynamics between crop diversification, financial management, and environmental factors on farm incomes. While the data suggests certain trends, such as the benefits of larger farm sizes and diversified crop strategies.

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APPENDIX

Figure 3 Geographical Distribution of Farm Numbers and Average Farm Income Per County

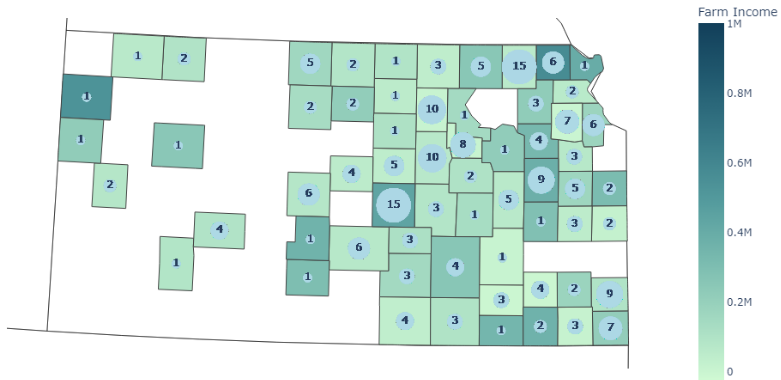

Figure 4: Comparative Density Plots of Adjusted Mean Farm Income for Crop-only and Mixed Farms Before and After 2012

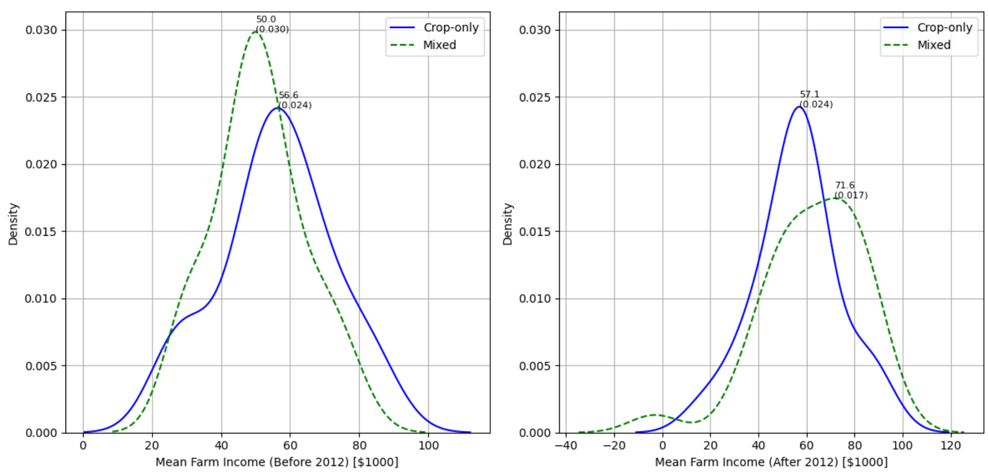

Table 2: Number of Crops with Financial Variables

Variable	1-2 crops	3-4 crops	4-6 crops	6 or more crops
Observations	671	1761	1382	1058
Crop Acres	1226.0 (945.4)	1451.5 (1161.0)	1457.9 (1044.3)	1479.2 (1005.9)
Debt-Asset Ratio	0.244 (0.260)	0.228 (0.247)	0.244 (0.233)	0.262 (0.225)
Farm Production ($k)	578.0 (549.0)	708.0 (684.0)	687.0 (643.0)	738.0 (606.0)
Net Farm Income ($k)	128.0 (207.0)	164.0 (230.0)	157.0 (228.0)	166.0 (200.0)
Government Payments ($k)	33.4 (41.5)	42.2 (51.9)	40.2 (43.9)	44.2 (48.6)
Insurance Income ($k)	27.1 (71.6)	32.9 (89.4)	32.2 (96.8)	30.1 (72.3)
Insurance Expense ($k)	16.7 (22.9)	19.2 (23.4)	17.2 (21.7)	16.8 (19.0)
Net Farm Income (No Support) ($k)	83.8 (210.0)	108.0 (223.0)	102.0 (218.0)	108.0 (199.0)
Total Livestock Income ($k)	103.0 (291.0)	97.5 (251.0)	190.0 (483.0)	286.0 (502.0)
Farm Income Per Acre ($)	112.4 (298.9)	123.7 (170.7)	112.8 (153.6)	124.1 (143.0)
FI (No Support) Per Acre ($)	71.3 (301.6)	84.3 (176.2)	74.6 (152.1)	85.8 (144.5)

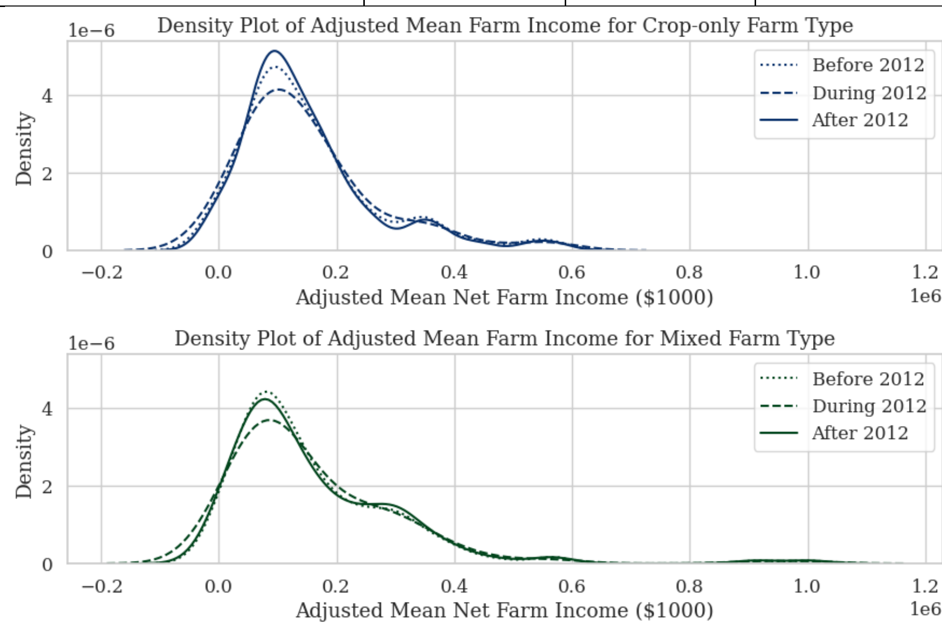

Figure 5 : Density Plots of Adjusted Mean Net Farm Income for Crop-Only and Mixed Farm Types: Before, During, and After 2012