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RESEARCH ARTICLE

The relationship between commodity diversification and the adoption of technological innovations for Southeast beef cattle producers

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Abstract

For almost eight decades, productivity in the United States agricultural sector has substantially increased, in large extent due to the adoption of technological innovations. Despite the increased utilization of technology, questions remain regarding which producers are more likely to adopt a greater number of technological innovations. This research seeks to understand how commodity diversification strategies, farm characteristics, producer perceptions of risk, conservation, information sources, climate adaptation, and producer demographic characteristics are associated with technology adoption among beef cattle producers in the Southeast United States. Utilizing data from an online survey and an Ordered Probit model, we show that beef cattle producers who also produce fruit have an increased probability of adopting a greater number of technologies. The opposite effect is found for other commodities such as vegetables, row crops, and other livestock. Policy recommendations are also discussed.

Keywords: Beef cattle; diversification; Southeast; technology adoption

JEL Codes: Q16 (agricultural technology)

Introduction

For almost eight decades (since 1940s), productivity in the United States (US) agricultural sector has substantially increased, despite a decline in the inputs (i.e. labor, land) used (Fuglie 2007; USDA-ERS 2024). A primary reason for this is the impact of technological innovations (Fuglie and Wang 2012). The impact of new technology is often highlighted through increases in the Total Factor Productivity (TFP). To further illustrate the role of technological innovations in agriculture, between 1960 and 2004, TFP was more important to output growth in agriculture compared to many other US industries (Fuglie 2007). Technology adoption has been shown to decrease farm production costs and increase profits (Michler et al. 2019) through yield gains, overcoming environmental limitations, mechanization, and automation (Sassenrath et al. 2008). In addition to positively influencing output productivity (Chavas and Nauges 2020), adoption of technology can benefit producers in terms of risk management (McFadden et al. 2023; Mundlak 2000; Pardey et al. 2010), especially in the face of increasing climatic, economic, social and production challenges faced by rural economies (Morris et al. 2017).

Due to the importance of technological innovation in determining agriculture productivity, several scholars have examined the factors that positively impact adoption rates. A common theme in this research is that beginning farmers are more likely to adopt technologies (Torres 2022). Moreover, farm size and input use such as labor requirements and machinery use have been found to positively impact adoption decisions (Schimmelpfennig 2016). Despite the well-documented benefits of technological innovations, adoption rates for specific technologies, such as precision agriculture information technologies (Schimmelpfennig and Ebel 2011), smartphones (Michels et al. 2020), or digital technologies (Groher et al. 2020) remain low. Several factors such as cost, prior knowledge, investment returns, uncertainty or deficiencies in liquidity, and lack of user-friendliness are among the most cited barriers to adoption from previous literature (Gillespie et al. 2007; Groher et al. 2020; Makinde et al. 2022; Rosa 2021).

Although there is a wealth of research on the adoption of technological innovations in agriculture (Dinar and Yaron 1992; Llewellyn and Brown 2020; Schimmelpfennig and Ebel 2011; Torres 2022), most literature focuses on single commodities or farm units (DeLay et al. 2022; Foster and Rosenzweig 2010) and primarily row crop and/or fruit and vegetable producers (Carletto et al. 2007; Issaka et al. 2021; Khan et al. 2022; Ochieng et al. 2022). Furthermore, the focus of this line of research is often on the adoption of a single technological innovation (Deichmann et al. 2016; Gupta et al. 2020; Komdeur and Ingenbleek 2021). These studies fail to capture how diversification might influence the adoption of technologies appropriate to multiple production systems.

Considering technology adoption among livestock producers specifically, previous studies focused on record keeping and data transmission which are beneficial for economic profitability, herd management, and outside traceability, i.e., ((Boyer et al. 2024; Dill et al. 2015; Hefley et al. 2023; Lazurko et al. 2024)). Pruitt et al. (2012) examined technology adoption on cow-calf operations and for several technologies[1] but did not consider the effects of production of multiple commodities. However, as Afi and Parsons (2023) indicated, multi-commodity beef cattle operations are different from operations that only produce beef cattle, given the complementary nature of crop-livestock systems. Nevertheless, to the best of our knowledge, only a few studies, including those referenced above, have examined whether technology adoption differs between producers who only produce beef cattle and multi-commodity beef cattle producers.

To fill the gap in the literature, we examine the relationship between diversification and technology adoption for a diverse group of beef cattle producers in the Southeastern US. We utilize a dataset of 140 beef cattle producers across 11 Southeastern states[2]. This region

[1]Considered implants and/or ionophores, artificial insemination, embryo transfer and/or sexed semen, regularly scheduled veterinary services, use of a nutritionist, forage testing, rotational grazing, use of a calving season, animal identification, individual cow/calf record keeping, computer recordkeeping, and Internet use.

[2]Following Rotz et al. (2019), Southeastern states surveyed included: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee and Virginia.

Table 1. Adoption rates for the selected technologies for Southeast beef cattle producers (from highest to lowest adoption)

#	Technologies	Adoption rate (%)
1	Smartphones/tablets for farm management	72 %
2	Computers to track or manage finances	67 %
3	Automated environmental controls for animal housing	42 %
4	Artificial insemination	39 %
5	Weather monitoring with weather stations	38 %
6	Automatic feeding or watering for animals	36 %
7	Estrus synchronization	21 %
8	Growth-promoting technologies (implants, ionophores)	20 %
9	GIS technology	15 %
10	Blockchain technology	7 %

Note: n = 140.

was selected because, historically cow-calf operations in the Southeast ranked second in the US in terms of the number of beef cattle and had the greatest number of individual operations (McBride 2011). Moreover, as of 2023, approximately 23% of the beef cattle herd can be found in the Southeast (USDA-NASS 2023).

We model diversification by identifying whether the operation also produces vegetables, row crops, fruit and orchard crops, other livestock, poultry, and forestry products. We examine how diversification is associated with the adoption of ten specific technologies (see Table 1). The selected technologies include innovations that would commonly only be adopted by livestock producers (five technologies[3]) and technologies useful when producing any of the other examined commodities (five technologies[4]). Understanding technology adoption across beef cattle producers with different commodities in production can aid in developing policies and practices to support technological advancement and increase adoption.

The outcome variable in this paper is the number of technologies beef cattle producers adopt. We use an Ordered Probit model to estimate the relationship between adoption and diversification, farm characteristics, producer perceptions of risk, conservation practice adoption, information sources, and producer characteristics. As a preview of our findings, diversification is associated with the number of technologies adopted. For example, if a beef cattle producer also produces fruit or orchard crops, they are more likely to adopt four or more technologies. Conversely, if a beef cattle producer diversifies their operation by producing forestry, other livestock, or row crops, they are more likely to adopt fewer than four technologies.

[3]Automated environmental controls for animal housing, artificial insemination, automatic feeding or watering for animals, estrus syncretization, and growth promoting technologies (implants, ionophores).

[4]Smartphones/tablets for farm management, computers to track and manage finances, weather monitoring with weather stations, GIS technology, and blockchain technology.

Methodology and data

Survey design

The data used in this study was obtained from an online survey of beef cattle producers in Southeastern US. The survey questionnaire was designed and administered through Qualtrics using computer assisted telephone interviewing (CATI) method.[5] The survey was pre-tested in January and February 2024 with cattle producers and Extension personnel. After pre-testing was complete, the survey was distributed between March and April 2024 in 11 SE states. The final dataset includes 140 completed responses. For analysis completed in this paper, we kept the responses that had credible answers for the questions used.

The survey instrument had three sections. The first section collected information about farm characteristics (i.e. the number of operations, number of pastures, total area in production, and if the operation had a pre-conditioning or stocker operation). This section also included questions to determine the types of commodities produced to form measures of diversification. A second group of questions examined producer perceptions, production goals, and risk management decisions. These included perceptions and enrollment in risk management programs, adoption of conservation practices, sources of information, operational risks, and their concerns about future events and adaptation strategies. Finally, a third section gathered information on producer demographic characteristics (e.g. marital status, level of education, age, gender, years of experience, etc.) and their risk attitude measured with four Likert scale questions. The survey instrument included attention-checking questions to increase response accuracy.

As discussed previously, respondents were asked to indicate their adoption of ten technologies (Table 1). The selection of technologies was based on previous research (Collins 2011; Gillespie et al. 2023; Pruitt et al. 2012; USDA-APHIS-VS 2011). In our empirical analysis, producers were asked to indicate if they adopted and currently utilize each of these practices. This removes the potential problem of counting disadopters or producers who adopted technology but do not currently use the listed technology.

Adoption rates for individual technologies ranged from 7% for blockchain to 72% for smartphones/tablets for farm management. Livestock-specific technologies such as automated environmental controls for animal housing, artificial insemination, estrus synchronization, or growth-promoting technologies showed lower rates of adoption compared to technologies such as smartphones used to manage the farm or computers to track or manage finances (Table 1).

Empirical strategy

To estimate the relationship between the number of technological innovations adopted by producer (i) and diversification among beef cattle producers in the sample, we utilized an Ordered Probit Estimation (consistent with Wollni et al. (2010) and Teklewold et al. (2013)). The variable of interest (y_i) is, besides diversification, explained by farm characteristics, producer perceptions of risk, conservation, information sources, climate adaptation, and producer demographic characteristics measures (X_i) based on the following equation:

$$y_i^* = \boldsymbol{X}_i'\beta + u_i \tag{1}$$

[5]Due to Qualtrics CATI methodology, the authors have no knowledge about recruitment strategy, response rate, incomplete responses, or other details to fully describe survey distribution. The IRB for this survey is IRB 2023-0044.

Table 2. Summary statistics for farm characteristics for Southeast beef cattle producers

Variable	Variable type	Mean	Min	Max
No. Operations	Continuous	1.33	1	4
No. Pastures	Continuous	8.28	2	80
Production Total Acres	Continuous	552.07	110	5000
Stocker	Binary	0.68	0	1
Produce Row Crop	Binary	0.21	0	1
Produce Vegetable	Binary	0.12	0	1
Produce Fruit	Binary	0.11	0	1
Produce Forest Products	Binary	0.09	0	1
Produce Poultry	Binary	0.14	0	1
Produce Other Livestock	Binary	0.33	0	1
Only Produce Beef	Binary	0.36	0	1

Note: n = 140.

where $i = 1, 2, \cdots, 140$, y_i^* is the latent variable capturing producer i's count of technologies adopted, X_i is a vector containing the independent variables including state fixed effects, β is a vector of parameters to be estimated, excluding the intercept, and u_i is the stochastic error that follows a Normal distribution with mean zero and variance 1, $u_i \sim N(0, 1)$. The relationship between the variable of interest (y_i) and the latent variable (y_i^*) is given by:

$$\begin{aligned} y_i &= 1 \quad if -\infty < y_i^* < \mu_1 \\ y_i &= 2 \quad if \quad \mu\_1 < y_i^* < \mu_2 \\ &\vdots \\ y_i &= 7 \quad if \quad \mu_6 < y_i^* < +\infty \end{aligned} \tag{2}$$

where $\mu_1, \cdots, \mu_7$ are the threshold parameters known as "cut-points" estimated jointly with the β. The data tabulation and the Ordered Probit estimation were completed in Stata 18 (commands *oprobit* and *margins*), and the standard errors were clustered at the date of the survey to control for any potential unobserved characteristics that might affect the estimation. Descriptive statistics of independent variables are displayed in Tables 2, 3, 4, and 5 and discussed in the next subsection.

To capture diversification, the survey included the question "*Which of the following do you produce?*" with the available options to select being: *beef cattle*, *poultry*, *other livestock*, *row crop*, *vegetables*, *fruit or orchard*, and *timber or forest products*. If an option was selected, respondents were asked to indicate the acreage for each commodity. In the final model, seven dummy variables were added to describe the operation in terms of producing row crop (*Produce Row Crop*), vegetable crops (*Produce Vegetable*), fruit and orchard crops (*Produce Fruit*), poultry (*Produce Poultry*), other livestock (*Produce Other Livestock*), timber or forest products (*Produce Forest Products*). Since all operations produce beef cattle, a dummy variable was added to characterize producers who only produced beef cattle (*Only Produce Beef*). Technology adoption might also be explained by farm location,

Table 3. Percentage of beef cattle producers in the sample adopting various numbers of technologies across different commodities produced

Number of technologies adopted[a]	Overall	Produce						
		Only Beef	Fruit	Row Crop	Other livestock	Forest	Poultry	Vegetables
1	6 %	8 %	7 %	7 %	2 %	0 %	0 %	6 %
2	17 %	18 %	0 %	26 %	15 %	17 %	16 %	18 %
3	28 %	24 %	33 %	23 %	30 %	25 %	11%	47 %
4	24 %	24 %	13 %	20 %	33 %	25 %	32 %	18 %
5	17 %	20 %	20 %	10 %	15 %	17 %	32 %	12 %
6	4 %	4 %	0 %	7 %	0 %	8 %	5 %	0 %
7	4 %	2 %	27 %	7 %	5 %	8 %	5 %	0 %
Average	3.58	3.5	4.47	3.47	3.61	4	4.16	3.12

Note: The column overall displays the overall share for all 140 Southeast beef cattle producers. The column Only Beef displays the share among beef cattle producers that only produce beef cattle. Columns to the right display the share for beef cattle producers that also produce Fruit, or Vegetables, or Row Crop, or Other Livestock, or Poultry and or Forest Products.
[a]Of the ten technologies included in the question, respondents reported adopting between one and seven of the ten technologies listed in the survey, with no respondents indicating the adoption of zero technologies or eight or more.

Table 4. Respondent perceptions of sources of information, threats to the operation, adaptation, and use of conservation practices

Variable	Variable type	Mean	Min	Max
No. of Conservation Practices	Continuous	3.31	1	6
No. of Adaptation Strategies	Continuous	3.2	1	6
Enrolled in Indemnity Program (1 = yes)	Binary	0.51	0	1
Sales Rep Most Accurate	Binary	0.07	0	1
Variation in Unexpected Expenses	Binary	0.24	0	1
Variation in Cattle Prices	Binary	0.48	0	1

Note: Respondents were asked to indicate the number of conservation practices they adopted as well as the number of adaptation strategies they would consider adopting. Both of these variables are the count of practices/strategies indicated. Another question asked respondents to indicate the perceived accuracy of production information. A variable to indicate sales representatives are most accurate is included as a binary variable. Other questions asked producers to select and/or indicate sources of risk and variation in net cash farm income. Respondents who indicated unexpected expense and or/ cattle prices in these questions were included as binary variables.

size, and if the operation has beef cattle stockers or a pre-conditioning program. We account for a pre-conditioning program or stocking operation with a binary variable equal to 1 if the producer indicated that they have a pre-conditioning program or stocking operation (*Stocker*). We also capture the number of pastures (*No. Pastures*), the total acreage in production (*Production Total Acres*), and the number of operations (*No. Operations*) that the owner operates. Respondents were instructed to "*Consider an*

Table 5. Summary statistics for beef cattle producer demographic characteristics

Variable	Variable type	Mean	Min	Max
Age (in years)	Continuous	44.91	27	67
Married (1 = yes)	Binary	0.69	0	1
Some College or Higher (1 = yes)	Binary	0.74	0	1
Beginning Farmer (10 years or less experience)	Binary	0.29	0	1
High Extension Interaction (<7 times)	Binary	0.09	0	1

Note: *Some College or Higher* is a binary variable equal to one if the respondent indicated they had more than a high school diploma. *High Extension Interaction* is a binary variable equal to one if the respondent indicated they had seven or more interactions with Extension either through agents or attendance at events in the last 12 months.

operation as a distinct production location more than 50 miles apart." To account for unobserved differences that may exist between states or cattle production across the region, we added state-fixed effects (10 dummy variables).

Producer perceptions of operational risk, conservation practices, information sources, and possible future climate adaptations might also affect adoption. Respondents were asked "Over the next 10 years, to what extent are you concerned with the following threats to your farm operation?" This included concerns about environmental and market risks (e.g. increased heat stress in livestock, longer dry periods and drought, increasing input costs, and decreasing cattle prices). A binary variable equal to 1 if the respondent indicated that they were "moderately concerned" or "extremely concerned" about decreasing cattle price being a threat to the farm operation over the next 10 years was added (*Variation in Cattle Prices*). Survey participants were also asked to evaluate the accuracy of information obtained by different sources with 1 being very low accuracy and 5 being very high accuracy[6]. A binary variable equal to 1 if the respondent ranked agricultural sales representatives highest or tied for the highest in terms of accuracy of agricultural production information (*Sales Rep Most Accurate*). In a subsequent question, producers were asked "In the last 3 years, what was the greatest source of variation on your net cash farm income for your largest beef cattle operation in the Southeast?" and instructed to select one source from a list of market and production sources[7]. A binary variable equal to 1 if the respondent stated that unexpected expenses were the greatest source of variation on their net cash farm income (*Variation in Unexpected Expenses*). Finally, respondents were asked, "In the last 3 years, did you enroll or receive payment from any of the following programs?" and required to indicate if they had enrolled and/or received a payment from various USDA programs[8]. A binary variable equal to 1 if the producer is enrolled in United States Department of Agriculture Livestock Indemnity Program (*Enrolled in Indemnity Program*).

We also added two variables to control for producers' willingness to adopt conservation practices and other management strategies used to lower the possibility of damage from

[6]Accuracy of information was compared to other sources including United States Department of Agriculture (USDA), other governmental agencies, other producers, YouTube, TikTok, other media sources and consultants.

[7]Respondents could select: cattle prices, input costs, forage availability and yield, loss of animals, unexpected expenses, or other and write in a response.

[8]A few of the programs included in the list were: NRCS Climate Smart Projects, NRCS Conservation Reserve Program, USDA Livestock Forage Program.

weather events. Adoption of conservation practices was measured as a count variable of the number of conservation practices adopted (*No. of Conservation Practices*). Possible conservation practices appropriate for beef cattle producers in the Southeast that respondents could indicate they used included: incorporation of legumes, poultry litter, silvopasture, forage stockpiling, biochar and incorporation of cool-season forage. Respondents were asked "How likely are you to implement any of the following practices to lower the possibility of damage from weather events?" Possible adaptation strategies appropriate for beef cattle producers in the Southeast included in the question were: irrigation, change in forage species, change in cattle genetics, take out more/better insurance policies, add additional water sources to pasture, and add additional shade to pasture. Then, a count variable of the number of adaptation strategies that a respondent answered "likely" or "very likely" to adopt was included as *No. of Adaptation Strategies*.

To control for producer demographic characteristics, we account for the respondent's *Age* as a continuous variable, whether she/he is *Married* as a binary variable (equal to 1 if the producer is currently married), and producer's education (*Some College or Higher*) as a binary variable equal to 1 if the producer has completed some college, obtained an associate's degree, bachelors, masters, PhD or any other professional degree. Last, we added a binary variable *Beginning Farmer* equal to 1 if the producer reported having 10 years or less experience in farming, to account for experience.

Farm characteristics and diversification

Table 2 reports summary statistics for the farm characteristics and diversification measures used to describe operations in the sample. The average size of the operation is 552 acres, with slightly more than 8 pastures. This is consistent with other studies that showed Southeast cattle operations are small, either measured in terms of acreage or total herd size, i.e., (Asem-Hiablie et al. 2018; McBride 2011). Previous studies have shown the prevalence of both joint cow-calf and stocker, and stocker-only operations as being the dominant operation structure for beef cattle operations across the Southeast (Asem-Hiablie et al. 2018; McBride 2011). For our sample, 68% of respondents indicated they have a stocker or pre-conditioning program.

More than 60% of respondents indicated that they produce commodities other than just beef cattle. The most common option as a second commodity group was another type of livestock, followed by row crops. Less common commodities produced included fruit or orchard crops (11%), vegetables (12%), and forest or timber products (9%). Further, approximately one-quarter of the sample was highly diversified, indicating they produce three or more commodities out of the seven available in the survey.

Table 3 displays the overall unconditional distribution of the technology adoption and the share (percentage) of respondents in each level (seven levels) with associated measures of diversification. Table S1 in the supplementary material, also displays the adoption of specific technologies, but by diversification measures. While the average number of technologies adopted was 3.58 technologies, differences exist between the number of technologies adopted based on commodity groups. Note that no one adopted zero technologies or more than seven technologies. Beef cattle producers who also produce fruit or orchard crops adopted an average of 4.47 of the listed technologies. The average number of technologies adopted is higher for this group of producers compared to beef cattle producers who also produce vegetables or beef producers who also produce row crops.

Producer perceptions

About half of the respondents are enrolled in the USDA Livestock Indemnity Program[9] and are concerned about cattle prices. We also find that the average producer in our sample adopts more than three of both the conservation practices and the practices implemented to combat damage from weather events. While conservation practice adoption and technology adoption are not synonymous, adoption decisions have been shown to be correlated for certain producer groups (Kolady and Van der Sluis 2021). Approximately, one quarter of respondent's state that the greatest variation in income is accredited to unexpected expenses. Given that technological innovations have been shown to be costly to adopt, the perceived source of income variation could be associated with adoption (Gillespie et al. 2007; Makinde et al. 2022; Rosa 2021).

Survey demographic characteristics

The demographic characteristics of our sample are presented in Table 5. The average age of the sampled producer is approximately 45 years, which is lower than the average age of US farmers (58.1 years) (USDA-NASS 2022); however, this is expected due to the online nature of the survey. Most of the survey participants are married and have attended at least some college. A small group of the sample (~10%) indicated they had 7 or more interactions with extension agents or attended Extension meeting, event, or field day in the last 12 months.

Results

The estimated coefficients and the marginal effect of the Ordered Probit model are reported in Table 6 below and Table A1 in the Appendix[10]. Sixteen out of twenty-two coefficients were statistically significant, including five out of seven on diversification[11].

In the following discussion, we will primarily focus on the marginal effects displayed in Figures 1,2,3,4 and 5. Consistent with our expectations, only producing beef cattle (no diversification) is associated with a lower likelihood of adopting more technologies or the number of technologies adopted. Specifically, this group of respondents is more likely to adopt three or fewer technological innovations (Figure 1).

This result is consistent with other research indicating that the level of diversification positively impacts the adoption of technologies, (i.e., (de Oca Munguia and Llewellyn 2020)). In terms of diversification, our findings suggest that if the operation included fruit production as part of the production activities, producers would have an increased likelihood of adopting a greater number of technologies (Figure 2). Specifically, beef cattle

[9]Respondents were asked if they had enrolled in the USDA Livestock Indemnity Program. Respondents could select "Did not enroll," "Enrolled, did not receive payment," or "Enrolled, received payment." Respondents were considered enrolled if they selected "Enrolled, did not receive payment" or "Enrolled, received payment."

[10]We have also estimated nested versions of this model excluding block of variables (producer and farm characteristics) to test whether the coefficients on diversification are consistent. Based on AIC and BIC, this is the preferred model, and results on diversification did not change drastically across models. Results of these models can be obtained upon request.

[11]Variables found to be statistically significant were: *Only Produce Beef, Produce Fruit, Produce Vegetables, Produce Other Livestock, Enrolled in Indemnity Program, No. Conservation Practices, Sale Rep Most Accurate, Variation in Unexpected Expenses, Variation in Cattle Prices, Beginning Farmer, Married, Stocker, No. Pastures, Production Total Acres, No. Operations.*

Table 6. Ordered probit regression model estimates

Ordered Probit Regression Model of Number of Technologies Adopted		
Independent Variables	Coefficients	Standard Errors
Diversification		
Produce Row Crop	−0.5950**	0.2536976
Produce Vegetables	−0.6349***	0.2399179
Produce Fruit	0.4074**	0.1723269
Produce Forest Products	0.5894	0.3702139
Produce Poultry	0.2398	0.2437003
Produce Other Livestock	−0.5027**	0.2324767
Only Produce Beef	−0.6478*	0.3620662
Producer perceptions		
Enrolled in Indemnity Program	0.4863**	0.189433
No. of Conservation Practices	0.2376**	0.1144341
Sales Rep Most Accurate	0.5060***	0.1633473
Variation in Unexpected Expenses	−0.3952*	0.2338135
Variation in Cattle Prices	0.3826*	0.2177796
No. Adaptation Strategies	0.1638	0.1026512
Producer characteristics		
Beginning Farmer	0.4755**	0.2135998
Married	−0.2836*	0.1716937
Some College or Higher	0.1053	0.3086327
Age	0.0146	0.0123918
High Extension Interaction	−0.7996	0.5860431
Farm characteristics		
Stocker	0.4393*	0.2474585
No. Pastures	0.0715***	0.0275638
Production Total Acres	−0.0004**	0.0001739
No. Operations	0.3821***	0.1350527
State Fixed Effects	Yes	
Observations	140	

Note: The dependent variable is the number of technologies adopted. Statistical significance of each independent variable is indicated by the following: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

producers who also produce fruit or orchard crops were found to be more likely to adopt four or more of the listed technologies.

Conversely, beef cattle producers who diversified operations by producing row crops, other livestock, and vegetables were found to be more likely to adopt fewer than four

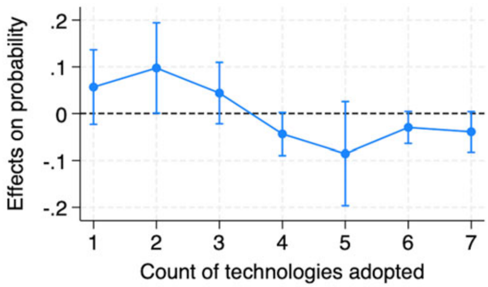

Figure 1. Marginal effect (and 95% confidence interval) of *only produce beef* using the estimated ordered probit (Table 6) for 140 Southeast beef cattle producers.

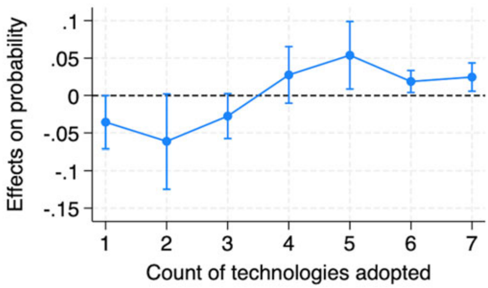

Figure 2. Marginal effect (and 95% confidence interval) of *produce fruit* using the estimated ordered probit (Table 6) for 140 Southeast beef cattle producers.

technologies (Figure 3). Contrary to previous results, no evidence of complementary technologies adopted by beef producers is evident in our sample.

Other factors related to producer's risk perceptions and strategies to manage risk that might also explain adoption (*Enrolled in Indemnity Program, No. of Conservation Practices, Sales Rep Most Accurate and Variation in Cattle Prices*) are displayed in Figure 4. We find that all were associated with an increased probability of adopting a greater number of technologies. Specifically, a producer who is enrolled in a risk protection program was found to be associated with a greater likelihood of adopting four or more of the selected technologies. The same is true for producers who implement conservation practices. Furthermore, the greater the number of conservation practices adopted, the greater the probability of adopting more technologies. Similar to other research finding correlations between technology and conservation practice adoption (Kolady and Van der Sluis 2021), this suggests that producers actively managing risk and/or adopting other practices might have similarities to those adopting a greater number of technologies.

Among producer characteristics, *Beginning Farmer* was statistically significant and shows that the probability of technology adoption increases if a producer has 10 years of experience or less. On the other hand, we find no statistically significant difference in technology adoption count based on age, education level, or the number of extension interactions.

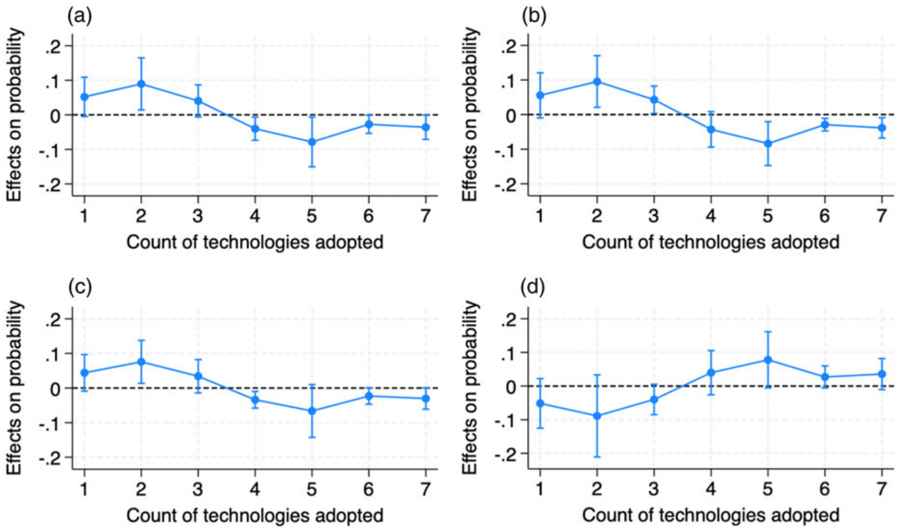

Figure 3. Marginal effect (and 95% confidence interval) of producing different commodities ((A) *Produce row crop*, (B) *Produce vegetables*, (C) *Produce other livestock*, (D) *Produce forest products*) using the estimated ordered probit (Table 6) for 140 Southeast beef cattle producers.

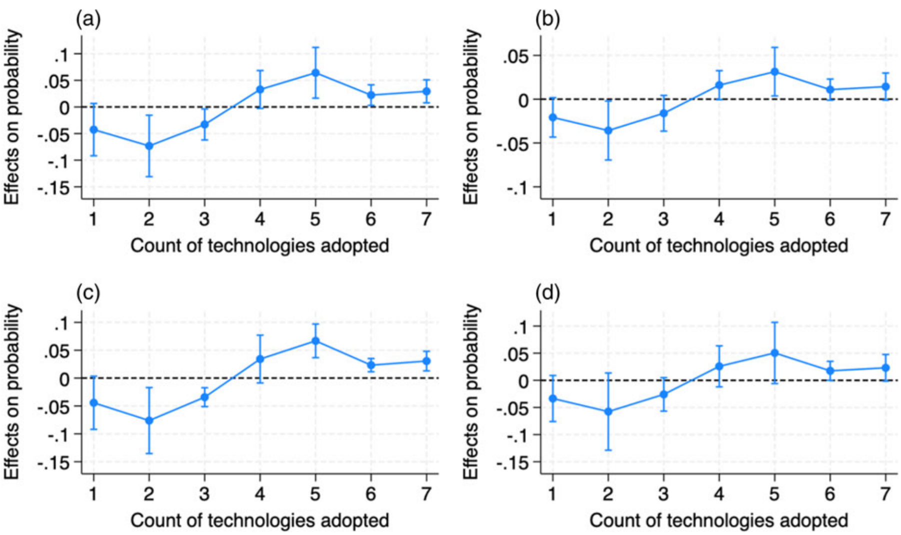

Figure 4. Marginal effect (and 95% confidence interval) of producing different commodities ((A) *Enrolled in Indemnity Program*, (B) *No. of Conservation Practices*, (C) *Sales Rep Most Accurate*, (D) *Variation in Cattle Prices*) using the estimated ordered probit (Table 6) for 140 Southeast beef cattle producers.

Farm characteristics were also found to be important to understanding technology adoption. Operation size, expressed as the number of pastures on the farm and whether the producer has a pre-conditioning or stocker operation, were associated with a higher probability of adopting more technologies (Figure 5).

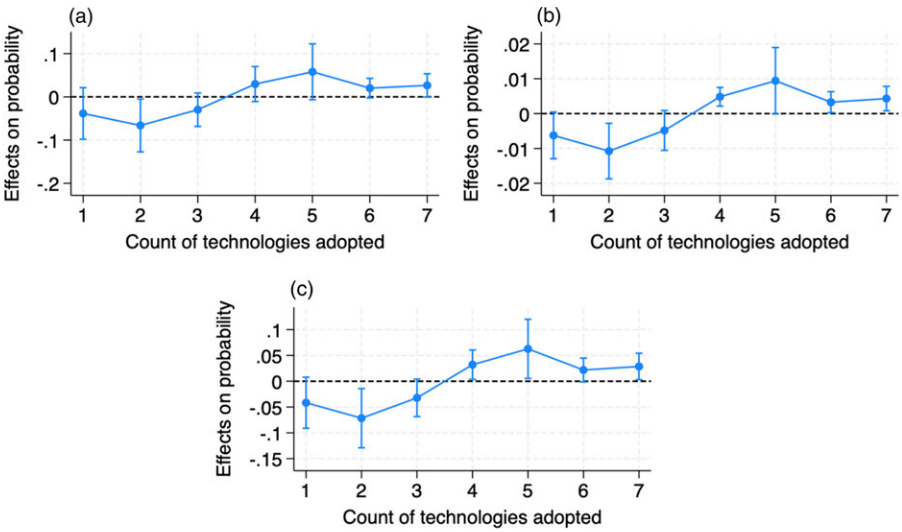

Figure 5. Marginal effect (and 95% confidence interval) of selected producer and farm characteristics ((A) *Stocker*, (B) *No. pastures*, (C) *Beginning Farmer*) using the estimated ordered probit (Table 6) for 140 Southeast beef cattle producers.

Robustness check

The discussion above focuses on one way of measuring diversification but we also considered other model specifications. First, instead of adding dummy variables for different commodity groups, we estimated the Ordered Probit model only controlling for producers who only produce beef. Results of this model are in the supplementary material Table S2, model alternative model #1(A.M.#1). We find consistent results, indicating that the lack of diversification is associated with the adoption of fewer technologies – although this variable is not statistically significant. Another way of measuring diversification is looking at the diversification intensity, which is measured as the share of the farmland devoted to commodities other than beef cattle. We added a continuous variable measuring the acres in production under different commodity groups to the model after removing all dummy variables measuring the status quo diversification measure. See Table S2 A.M. #2 for the estimated coefficients. We find consistent results, suggesting that the lack of diversification results in the adoption of fewer technologies. Additional steps were taken to define variables that may show reasons for technology adoption considering commodity diversification. We tested a variable in the model that accounted for the share of land dedicated specifically to beef cattle. This variable was not statistically significant.

In addition to the previous estimations, we also tested the interactions of: (1) poultry and other livestock and, (2) row crops and forestry, since there is a possibility that similarities among diversifying options can lead to the adoption of more technological innovations. Three models were estimated with different combinations of these interactions. The results are displayed in Table S2. Results indicate that these interactions do not impact adoption numbers and that synergies among commodities do not play a role in greater adoption numbers.

Finally, the nature of our dependent variable could also be seen as count variable, which could be estimated using Poisson regression. The results of this approach are in the

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supplementary material (Table S3). Results are generally consistent with what we find using Ordered Probit. We prefer the latter because it does not assume an equal probability of adoption (Teklewold et al. 2013; Wollni et al. 2010).

Conclusions

Technological innovations have historically contributed to output growth of the US agricultural sector. Due to the importance of technology to productivity gains, several studies have examined factors and barriers to adoption among US producers (Gillespie et al. 2007; Makinde et al. 2022; Rosa 2021). However, most of this research focuses mainly on adoption of a single technology or enterprise. This study adds to the literature by examining technology adoption decisions of beef cattle producers and considers the association with production of other commodities.

This research seeks to understand how specific commodity diversification strategies, captured by commodity production, are associated with the number of technologies adopted by beef cattle producers in the Southeast US. We show that diversification is associated with technology adoption. Beef cattle producers who don't diversify production are less likely to adopt more technologies. Moreover, a producer who produces fruit in addition to beef cattle is likely to adopt a greater number of technologies on the operation while a producer who produces row crops, vegetables or other livestock in addition to beef cattle is less likely to adopt a greater number of technologies. Enrollment in the USDA livestock indemnity program, implementation of other conservation practices, and having concerns about cattle price increase the probability of technology adoption for this group of producers. The same is found when a producer has 10 years or less experience and increases based on different proxies for operation size.

For beef producers and researchers, this study reinforces the importance of considering technology adoption through the lens of existing farm structure and commodities produced. These results become even more important as producers look to simultaneously increase output while addressing challenges such as market volatility, input scarcity, and environmental pressures. Considering these results into outreach and educational efforts, extension programs play a crucial role in facilitating the adoption of beneficial and applicable technologies (Batz et al. 1999; Zhou et al. 2008). By integrating these findings into outreach efforts, extension services can better support producers in identifying and implementing technologies that are suited for their operation. Both extension and policy incentives could enhance the reach of technology adoption programs. These findings suggest opportunities for researchers and lawmakers alike in developing incentives and programs that simultaneously promote commodity diversification and adoption of specific technologies.

One of the limitations of this study is that this dataset consists of 140 producers. Future research could focus on obtaining a larger sample size. Further, accurate measures of farmer income and/or farm revenues and profits were not obtained from the survey, and financial variables that may influence both commodity diversification and technology adoption were not captured. Given that many technology adoption decisions are high-cost with returns over multiple years, understanding producers' financial knowledge, decision-making, and farm financial health would likely provide valuable insights into adoption decisions. Lastly, the timing of this study must be considered. Market conditions and producer preferences can shift depending on the study period. During our study period, we saw a high cattle price environment, potentially increasing producer revenues and sentiment, which could have influenced farm financial conditions and, in turn, investment decisions. These general market conditions could have influenced responses to survey questions, including those related to perceptions of risk and long-term threats to the operation. As such, recognizing that producers responded to the survey during a period of high prices adds nuance to our findings and underscores the need for caution when generalizing our results beyond the specific timeframe of the study.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/age.2025.5

Data availability statement. The survey data used in this research is confidential. However, code is available upon request.

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Appendix

Table A1. Marginal effects tables for Ordered Probit Regression Model

	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
Stocker	−0.0384	−0.0661**	−0.0297	0.0296	0.0580*	0.0202*	0.0265*
	(−1.26)	(−2.12)	(−1.51)	(1.44)	(1.76)	(1.74)	(1.92)
No Pastures	−0.0063*	−0.0108***	−0.0048*	0.0049***	0.0094*	0.0033**	0.0043**
	(−1.83)	(−2.64)	(−1.66)	(3.52)	(1.94)	(2.14)	(2.42)
Production Total Acres	0.0000*	0.0000**	0.0000	−0.0000***	−0.0000**	−0.0000**	−0.0000**
	(1.85)	(2.54)	(1.62)	(−3.15)	(−2.01)	(−2.15)	(−2.07)
Enrolled in Indemnity Program	−0.0425*	−0.0732**	−0.0329**	0.0328*	0.0642***	0.0223**	0.0293***
	(−1.70)	(−2.49)	(−2.22)	(1.81)	(2.64)	(2.27)	(2.66)
No Operations	−0.0334**	−0.0575***	−0.0259	0.0258***	0.0504***	0.0175**	0.0231**
	(−2.29)	(−2.88)	(−1.64)	(3.13)	(2.58)	(2.17)	(2.21)
No. of Conservation Practices	−0.0208*	−0.0358**	−0.0161	0.0160*	0.0314**	0.0109*	0.0143*
	(−1.81)	(−2.08)	(−1.55)	(1.91)	(2.22)	(1.77)	(1.82)
Sales Rep Most Accurate	−0.0443*	−0.0762**	−0.0342***	0.0341	0.0668***	0.0232***	0.0305***
	(−1.82)	(−2.52)	(−3.97)	(1.56)	(4.34)	(3.85)	(3.42)
High Extension Interaction	0.0700	0.120	0.0541	−0.0539	−0.106	−0.0367	−0.0483
	(1.30)	(1.26)	(1.18)	(−1.03)	(−1.38)	(−1.49)	(−1.41)
Variation in Unexpected Expenses	0.0346	0.0595	0.0267	−0.0267	−0.0522*	−0.0181	−0.0239
	(1.51)	(1.55)	(1.55)	(−1.36)	(−1.96)	(−1.58)	(−1.46)
Variation in Cattle Prices	−0.0335	−0.0576	−0.0259*	0.0258	0.0505*	0.0176**	0.0231*
	(−1.55)	(−1.58)	(−1.65)	(1.34)	(1.75)	(1.97)	(1.84)
No. Adaptation Strategies	−0.0143	−0.0247	−0.0111*	0.0110	0.0216*	0.0076*	0.0099
	(−1.30)	(−1.44)	(−1.70)	(1.13)	(1.76)	(1.75)	(1.53)
Beginning Farmer	−0.0416*	−0.0716**	−0.0322*	0.0321**	0.0627**	0.0218*	0.0287**
	(−1.65)	(−2.45)	(−1.73)	(2.20)	(2.14)	(1.85)	(2.19)
Married	0.0248	0.0427*	0.0192	−0.0191**	−0.0374	−0.0130	−0.0171
	(1.63)	(1.68)	(1.09)	(−1.97)	(−1.38)	(−1.50)	(−1.54)
Some College or Higher	−0.0092	−0.0158	−0.0071	0.0071	0.0139	0.0049	0.0063
	(−0.35)	(−0.34)	(−0.33)	(0.35)	(0.34)	(0.34)	(0.34)
Age	−0.0013	−0.0022	−0.001	0.001	0.0019	0.0007	0.0009
	(−1.08)	(−1.24)	(−1.02)	(1.18)	(1.14)	(1.17)	(1.21)
Produce Row Crop	0.0521*	0.0896**	0.0403*	−0.0401**	−0.0785**	−0.0273**	−0.0359**
	(1.79)	(2.33)	(1.70)	(−2.35)	(−2.14)	(−2.04)	(−2.00)

(*Continued*)

Table A1. (*Continued*)

	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
Produce Vegetables	0.0555*	0.0956**	0.0430**	−0.0428	−0.0838***	−0.0291***	−0.0383**
	(1.67)	(2.51)	(2.13)	(−1.63)	(−2.59)	(−3.12)	(−2.56)
Produce Fruit	−0.0356**	−0.0613*	−0.0276*	0.0275	0.0538**	0.0187**	0.0246**
	(−1.96)	(−1.90)	(−1.80)	(1.42)	(2.33)	(2.49)	(2.55)
Produce Forest Products	−0.0516	−0.0887	−0.0399*	0.0398	0.0778*	0.0270	0.0356
	(−1.37)	(−1.43)	(−1.73)	(1.19)	(1.83)	(1.62)	(1.51)
Produce Poultry	−0.0210	−0.0361	−0.0162	0.0162	0.0316	0.0110	0.0145
	(−1.01)	(−0.91)	(−0.94)	(0.94)	(1.00)	(0.93)	(0.91)
Produce Other Livestock	0.0440	0.0757**	0.0340	−0.0339***	−0.0663*	−0.0231*	−0.0303*
	(1.63)	(2.39)	(1.38)	(−2.75)	(−1.70)	(−1.92)	(−1.93)
Only Produce Beef	0.0567	0.0975**	0.0438	−0.0437*	−0.0855	−0.0297*	−0.0391*
	(1.39)	(1.97)	(1.31)	(−1.87)	(−1.51)	(−1.71)	(−1.78)

N = 140.
*p<0.1 **p<0.05 ***p<0.01.

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