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Diffusion of Innovation, Internet Access, and Adoption Barriers for Precision Livestock Farming among Beef Producers

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Abstract

This study examined the relationship between internet access type and perceptions of Precision Livestock Farming (PLF) Technologies among beef producers in a specific state. Using data collected from an internet-based survey of beef producers (*n* = 137), this study conducted an exploratory factor analysis to construct variables corresponding to Diffusion of Innovation (DOI) attributes that influence innovation adoption. Findings indicate producers with cable, cellular, and broadband internet access had more favorable perceptions of PLF technologies in terms of barriers to adoption, while those with no internet access or satellite connections reported higher perceived complexity with the use of PLF technologies. Trialability and observability varied across internet types, suggesting hands-on experience and practical demonstrations might be more impactful for certain groups. Beef producers with satellite internet connections were more likely to perceive the need to trial PLF technologies before adoption. This study highlights the importance of internet access in rural areas and its potential impact on the adoption of PLF technologies, offering valuable insights for industry stakeholders and policymakers to promote the adoption of PLF technologies.

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Introduction and Problem Statement

Precision Livestock Farming (PLF) is a data-driven management approach that uses technology to optimize livestock performance and well-being. These technologies have the potential to benefit the livestock industry by enhancing animal welfare, increasing productivity, and reducing the environmental footprint of livestock operations (Berckmans, 2017; Neethirajan, 2017). In recent years, there has been growing interest in understanding the factors that influence the adoption of these technologies among livestock producers (Banhazi et al., 2012; Eastwood et al., 2019).

Internet access and connectivity are crucial for the successful implementation of PLF technologies, as they facilitate real-time monitoring and analysis of data. However, the availability and quality of internet access may vary among beef producers, potentially influencing their perceptions of PLF technologies and consequentially their adoption of PLF technologies (Groher, 2020). For instance, rural areas often have limited internet connectivity, which may act as a barrier to technology adoption (Vogels, 2021).

Studies have identified several factors that influence the adoption of PLF technologies, including the cost of the technology, perceived ease of use, perceived usefulness, and compatibility with existing systems (Boehlj & Langemeier, 2021; Fastellini & Schillaci, 2020). Additionally, the availability of technical support, training, and knowledge sharing can significantly impact the adoption process (Läpple & Kelley, 2013; Rose et al., 2016). Moreover, social factors, such as the influence of peers, local networks, and the role of extension services, can also affect the adoption of farming technologies (Ramirez, 2013). Examination of the influence of internet access type on PLF technology adoption among beef producers, however, has been limited to date.

An improved understanding of the technology-related factors that influence producers' PLF technology adoption decisions is crucial for developing targeted strategies to facilitate the adoption of PLF technologies among beef producers. By addressing these barriers and tailoring support and interventions to suit the specific needs of producers, it is possible to enhance animal welfare, increase productivity, and reduce the environmental impact of livestock operations.

Theoretical and Conceptual Framework

The Diffusion of Innovation (DOI) theory has served as a foundation for research on technology adoption for several decades. Developed by Rogers (1962), this theoretical framework has proven useful in understanding how and why individuals and organizations adopt new technologies. By examining the five key attributes of a technology that affect adoption—complexity, compatibility, relative advantage, trialability, and observability—researchers can gain insights into the adoption process and identify potential barriers or facilitators (Miller, 2015).

Complexity, as an attribute of DOI theory, has been widely studied, with research indicating that technologies perceived as less complex are more likely to be adopted (Tornatzky & Klein, 1982). This is because potential adopters may be hesitant to adopt a technology that they perceive as difficult to learn or use (Venkatesh et al., 2016).

Compatibility is another essential attribute, as it addresses how well the new technology aligns with the existing values, needs, and practices of potential adopters (Tornatzky & Klein, 1982). Studies have shown that technologies that are more compatible with current practices are more likely to be adopted (Miller, 2015).

Relative advantage, or the perceived benefit of the technology compared to existing alternatives, is a critical component of technology adoption (Miller, 2015). Research has demonstrated that potential adopters are more likely to adopt a technology when they perceive it to have a significant advantage over alternatives (Tornatzky & Klein, 1982). This can include benefits such as increased efficiency, cost savings, or improved performance (Moore & Benbasat, 1991). Cost-benefit analysis is often a consideration in determining the relative advantage of technology adoption, with expense being an important factor to weigh (Miller, 2015). As Rogers notes, the cost of technology is an important factor to consider, as adopters will perform a cost-benefit analysis that will ultimately influence adoption decisions (Rogers, 1962).

Trialability, the ease with which potential adopters can test or experiment with the technology, has been shown to influence adoption rates (Miller, 2015). When potential adopters can try out a technology before adopting, they are more likely to understand the benefits and make a more informed adoption decision (Venkatesh et al., 2003). This is especially relevant for complex technologies, where hands-on experience can help to reduce perceived complexity (Moore & Benbasat, 1991).

Lastly, observability is the extent to which the results of using the technology are visible to others (Rogers, 1962). Technologies with higher levels of observability tend to have higher adoption rates, as potential adopters can see the benefits firsthand and are more likely to be persuaded by the success of others (Miller, 2015).

Diffusion of Innovation theory provides a comprehensive framework for understanding the PLF technology adoption process, including the perceived barriers to PLF adoption among beef producers. An improved understanding of how producers perceive individual PLF technologies with respect to the five DOI attributes (complexity, compatibility, relative advantage, trialability, observability), and whether and how these perceptions are influenced by internet connection type, can inform the design, manufacturing and marketing of PLF technologies and enable researchers and practitioners to better facilitate their successful adoption.

Purpose

The purpose of this study was to understand the barriers to the adoption of PLF technologies among beef producers in Tennessee and how these barriers differ across various types of internet access. The specific objectives of this study were to: (a) identify the DOI attributes that may serve as barriers to the adoption of PLF technologies among beef producers in Tennessee, (b) explore potential differences in the perceived barriers to PLF technologies adoption across different types of internet access, and; (c) assess the relationship between the type of internet access and the importance of perceived barriers to adopting PLF technologies.

Methods

Survey Design and Procedure

This study collected data from a survey promoted via email in 2022 among Tennessee beef cattle producers and administered using the Qualtrics online survey platform. The survey targeted producers who participated in the Tennessee Agriculture Enhancement Program, a cost-share program that assists Tennessee agricultural producers in making long-term investments in their operations, and was designed to elicit respondent perceptions toward various PLF technologies and identify factors that influence their adoption. A pretest sample was first used to test the survey instrument and obtain feedback from producers to incorporate into the final version of the survey; it included six sections that addressed livestock numbers, farm size, cattle marketing, perceptions and use of PLF technologies, risk preferences, and socio-demographic information. Out of the 6,858 producers contacted by email, a total of 201 responses were received. After removing respondents who did not complete responses to the PLF barrier and internet type questions, a total of 137 complete responses were retained for analysis.

Exploratory Factor Analysis

Factors perceived to be barriers to the adoption of PLF technologies were elicited with the question: “To what extent do you agree or disagree that the following are barriers associated with using any Precision Livestock Farming Technologies on your operation?” Ten potential barriers were provided and rated on a Likert scale of agreement (1 = Strongly disagree, 5 = Strongly agree). The importance of having real time continuous information on 11 specific aspects of respondents' operations was rated on a 7-point scale of agreement (1 = Not important, 7 = Extremely important) and elicited with the statement: “Rate the importance of having real-time, continuous information for your operation for the following.”

Factors representing the five DOI attributes were extracted from survey responses using principal component analysis (PCA) (Watkins, 2018). Variables with high factor loadings, an indication of a strong relationship between them, were grouped under the same factor (Watkins, 2018). Variables representing each DOI attribute were then constructed by averaging the values of the variables comprising the respective attribute groupings.

Descriptive Analysis

Descriptive statistics were calculated to determine the distribution of internet access types among the surveyed beef producers in Tennessee and their perceived barriers to adopting PLF technologies. Cross-tabulation analysis was performed to examine the distribution of the barriers to adoption across different internet access types. Chi-square tests were used to determine whether observed differences in the distribution of barriers across internet access types were statistically significant (Upton & Cook, 2001).

Multivariate and Post-hoc Tests

Multivariate tests, including multivariate analysis of variance (MANOVA) and multivariate regression analysis, were conducted to assess whether the type of internet access significantly influenced the perceived barriers to adoption among Tennessee beef producers (Warne, 2014). Univariate tests, including ANOVA and multiple regression analysis, were used to examine the relationships between internet access types and each constructed DOI variable separately (Cardinal & Aitken 2005). Post-hoc tests, including Tukey's Honestly Significant Difference and Scheffé's test, were used to examine pairwise comparisons between different internet access types to identify which specific internet access types significantly differed from each other in terms of their influence on the DOI variables (Abdi & Williams, 2010; Klockars & Hancock 2000).

Findings

EFA Results

In this study, we aimed to construct variables representing the five DOI attributes (complexity, compatibility, relative advantage, trialability, and observability) to better understand the barriers related to the adoption of PLF Technologies among Tennessee beef producers.

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's Test of Sphericity were used to assess the suitability of the data for factor analysis (Dziuban & Shirkey, 1974; Tobias & Carlson 1969). The rotated component matrix (Table 1) was used to interpret the factor loadings, which represent the correlations between the variables and the extracted factors. Variables with high factor loadings (ideally greater than 0.4 or 0.5) were grouped under the same factor.

Table 1

PLF Technology Barriers Rotated Component Matrix

	Component				
	1	2	3	4	5
The technologies are too complex for my employees to learn	.862	.201	.028	.077	.024
The technologies are too complex for me to learn	.857	.217	.192	.088	.071
I need to be able to try out the new technology before committing to it	.665	.044	.510	.081	.036
I don't have enough time to learn the new system	.122	.892	.045	.145	.155
I need to see the technology working on a farm before I consider it	.234	.851	.242	-.039	-.023
My operation is too small to benefit from these tools	.136	.143	.893	.118	.101
I am not sure the technology fits with my production operations	.289	.555	.628	.008	-.102
I don't have good internet	.106	.046	.087	.957	.004
The technologies are too expensive	.192	.200	.158	.083	.842
I do not trust that my data stay private	.248	.301	.238	.335	-.502

The final allocation of items to the DOI variables was determined as follows (Table 2):

Table 2

DOI Variables and Items

DOI Barrier Variable	Item(s)
Complexity	
The technologies are too complex for me to learn	(Barriers_complexforme)
The technologies are too complex for my employees to learn	(Barriers_complexforemployees)
I don’t have enough time to learn the new system	(Barriers_time)
Compatibility	
I am not sure the technology fits with my production operations	(Barriers_unsure)
My operation is too small to benefit from these tools	(Barriers_smalloperation)
Relative Advantage	
The technologies are too expensive	(Barriers_expensive)
Trialability	
I need to be able to try out the new technology before committing to it	(Barriers_trytech)
Observability	
I need to see the technology working on a farm before I consider it	(Barriers_seetechwork)

Descriptive Statistics

In the descriptive and selection phase for internet types, we aimed to understand the distribution of various internet access types among beef producers in Tennessee who participated in the survey. The binary variables representing the internet types were no internet, DSL, broadband, cable, satellite, and cellular. No participant selected dial-up, so this variable was removed from the analysis.

Cellular was the most common type of internet service among respondents, followed by broadband and cable. Fewer respondents reported having DSL, satellite, or no internet service with the least common type of internet service among respondents being satellite (Table 3).

Table 2

Frequency of Internet Types Among Respondents (n = 137)

Internet Type	Frequency
Cellular	55
Broadband	37
Cable	20
DSL	16
No internet	16
Satellite	15

*Respondents may have selected more than one internet type

We attempted to determine whether specific barriers to technology adoption were associated with certain types of internet access by comparing the constructed DOI variables (Complexity, Compatibility, etc.) across the different internet types. As some respondents selected more than one type of internet, each type was examined independently. This is discussed further in the findings. Perceived complexity and compatibility of PLF technologies were lower for respondents with broadband (2.42, *SD* = 0.98), DSL (2.38, *SD* = 1.11), and cable (2.72, *SD* = 0.82) connections compared to no internet access (complexity: 2.77, *SD* = 0.88; compatibility: 3.34, *SD* = 0.79) and satellite (complexity: 2.80, *SD* = 1.30; compatibility: 2.93, *SD* = 1.28) (Table 4)

Table 3

Internet Types and Barrier Variable Means

Internet Type	Complexity	Compatibility	Relative Advantage	Trialability	Observability
No internet access	2.77	3.34	3.81	4.38	4.06
	(0.88)	(0.79)	(1.05)	(0.72)	(0.85)
DSL	2.38	2.91	3.38	3.69	3.44
	(1.11)	(0.95)	(1.15)	(1.20)	(1.21)
Broadband	2.42	2.99	3.70	4.08	3.59
	(0.98)	(0.92)	(0.70)	(0.98)	(1.12)
Cable	2.72	3.40	3.40	4.10	4.00
	(0.82)	(1.14)	(1.10)	(1.12)	(1.17)
Satellite	2.80	2.93	3.40	3.20	3.20
	(1.30)	(1.28)	(1.40)	(1.21)	(1.08)
Cellular	2.39	3.05	3.60	4.00	3.75
	(1.00)	(1.09)	(1.10)	(1.12)	(1.31)

Note. Standard deviation in parentheses

Relative advantage was rated highest by respondents with no internet access (3.81, SD=1.05), followed by those with cable (3.40, *SD* = 1.14), cellular (3.60, *SD* = 1.10), broadband (3.70, *SD* = 0.70), DSL (3.38, *SD* = 1.15) and satellite (3.40, *SD* = 1.40).

Trialability was rated highest by respondents with no internet access (4.38, *SD* = 0.72), followed by cable (4.10, *SD* = 1.12), broadband (4.08, *SD* = 0.98), cellular (4.00, *SD* = 1.12), DSL (3.69, *SD* = 1.20) and satellite (3.20, *SD* = 1.21).

Observability was rated highest by respondents with no internet access (4.06, *SD* = 0.85), followed by those with cable (4.00, *SD* = 1.17), cellular (3.75, *SD* = 1.31), broadband (3.59, *SD* = 1.12), DSL (3.44, *SD* = 1.21) and satellite (3.20, *SD* = 1.08).

In general, findings suggest perceived barriers to the adoption of PLF technologies decrease as the type of internet access becomes faster and more reliable. For example, the mean scores for complexity, compatibility, relative advantage, trialability, and observability are generally lower for broadband and cable internet compared to no internet access and DSL. Respondents with cable, cellular, and broadband internet access tend to have more favorable perceptions of PLF technologies, suggesting that access to these types of connections may encourage producers to adopt these technologies. Respondents with no internet access or a satellite connection rated complexity relatively higher than those with faster and more reliable types of access, suggesting technology adoption may be impacted by concerns among these groups regarding their ability to learn to use the technology.

The importance of trialability and observability varies across internet types, with respondents having no internet access or using cable, cellular, and broadband connections placing a higher emphasis on these factors. This implies that hands-on experience and practical demonstrations of PLF technologies might be more impactful for these groups. Respondents with broadband, DSL, and cable connections rated perceived complexity and compatibility relatively lower.

Multivariate and Post-hoc Tests

This analysis applied the Pillai's Trace test, as it is the most robust against violations of assumptions (Pillai & Sudjana, 1975); the results across all multivariate tests were consistent (Table 5).

Table 4

Pillai's Trace Results

Internet Type	F(df1, df2)	p-value
Cellular	0.901(5, 131)	0.483
Broadband	0.974(5, 131)	0.436
Cable	0.832(5, 131)	0.529
DSL	0.222(5, 131)	0.952
No internet	0.695(5, 131)	0.628
Satellite	2.390(5, 131)	0.041

From these results, there is a significant difference in the DOI variables between the different internet types only for satellite internet (p = 0.041). For all other internet types, the p-values are greater than the typical significance level of 0.05, indicating no significant difference in the DOI variables.

To better understand the specific differences between the satellite internet type and the others, this study conducted post-hoc tests, including Tukey's HSD (Klockars & Hancock, 2000). The post-hoc tests identified which specific pairwise comparisons were significantly different. Based on the between-subjects effects for the satellite internet type, the only significant effect was found for the dependent variable "PLF Technology barriers – I need to be able to try out the new technology before committing to it" (F = 7.209, p = 0.008). The other dependent variables did not show a significant effect.

ANOVA analysis indicated a significant effect of the independent variable "Internet satellite" on the dependent variable "PLF Technology barriers – I need to be able to try out the new technology before committing to it", $F(1, 135) = 7.209$, p = 0.008, partial eta-squared = 0.051. The "Type III Sum of Squares" for the independent variable was 8.725, with one degree of freedom and a mean square of 8.725. The "Partial Eta Squared" value of 0.051 indicated that approximately 5.1% of the variance in the dependent variable can be explained by the independent variable, after controlling for the effect of any other variables in the model.

Overall, the results suggest that exposure to satellite internet has a statistically significant effect on participants' reported technology barriers, specifically their need to be able to try out new technology before committing to it. However, the effect size is relatively small, accounting for only about 5.1% of the variance in the dependent variable.

Conclusions, Discussion, and Recommendations

In this study, analysis accounted for the fact that respondents, based on their diverse working environments, may have access to more than one type of internet service. For instance, a producer might primarily utilize cellular internet in a production environment and a different type when working from an office. With this in mind, each internet type was treated as an independent variable in our multivariate analyses. This approach controlled for potential confounding variables, including instances of multiple internet access types, thereby reducing interference from other types. Subsequently, post-hoc tests were employed to statistically ascertain the differences in perceptions of PLF technologies across various internet types. These tests served dual purposes - they provided a deeper understanding of the unique impact of each internet type and also served to reconfirm the validity of our multivariate analyses. However, it is acknowledged that this method does assume a primary internet type for each producer, which may not always be the case given the possibility of multi-ISP usage. This represents an interesting dimension for future research. Exploring the specific patterns of multi-ISP usage among beef producers, and understanding how it influences their perception of PLF technologies, could yield important insights into the intricacies of technology adoption in this sector.

The analysis revealed that respondents with cable, cellular, and broadband internet access generally have more favorable perceptions of PLF technologies, suggesting that access to these types of connections may encourage PLF technology adoption. On the other hand, respondents with no internet access or satellite connections reported a higher perceived complexity with respect to PLF technologies, which could serve as a barrier to their adoption. The importance of trialability and observability varied across internet types. Respondents with no internet access or using cable, cellular, and broadband connections placed a higher emphasis on these factors, implying that hands-on experience and practical demonstrations of PLF technologies might be more impactful for these groups. This corresponds with prior DOI research (Miller, 2015), and confirms that trialability and observability are key factors in the technology adoption process.

The findings of this study are consistent with similar studies examining the adoption of PLF in the beef (Makinde et al., 2022), sheep (Kaler & Ruston, 2019), and swine (Akinyemi et al., 2023) industries and have significant implications for the adoption of PLF technologies and the impact of internet access in rural areas. By understanding the relationships between internet access types and perceptions of technology adoption, industry stakeholders and policymakers can design more targeted and effective interventions to promote the uptake of PLF technologies among agricultural producers. By focusing on improving internet access and connectivity, as well as addressing the specific barriers to adoption faced by producers with different internet access types, policymakers can contribute to the overall growth and competitiveness of the agricultural industry.

These findings can be applied by industry stakeholders, such as technology providers, agricultural extension services and farmer organizations to better understand and address the needs of their target audiences. Consideration of the diverse range of internet access types among producers and the potential influence of access type on technology adoption can inform the development of effective strategies to facilitate the diffusion of PLF technologies and enhance the overall productivity and sustainability of the agricultural sector.

Furthermore, these results suggest that targeted interventions and support, such as financial incentives, educational programs, and technology demonstrations might be more effective in promoting the adoption of PLF technologies among producers with different types of internet access (Pruitt et al., 2012). For instance, addressing cost barriers and providing opportunities for trialability and observability for certain users could improve their likelihood of adopting these technologies.

In addition, policymakers and agricultural extension services should consider the specific needs and preferences of producers with different internet access types when designing and implementing initiatives to promote PLF technology adoption. This may include tailoring the content and delivery of educational materials and support services to suit the communication preferences and technological capabilities of producers with various internet access types.

This study has several limitations that should be considered when interpreting the results. First, the sample size is relatively small, and the findings may not be generalizable to all beef producers in Tennessee or other rural areas. Second, the study relied on self-reported data, which may be subject to biases, such as social desirability bias (Vesely & Klöckner, 2020) and recall bias (Tarrant et. al, 1993). Lastly, the study explored the relationship between internet access types and perceptions of PLF technology adoption but did not delve into the underlying reasons for these relationships. Future research should aim to replicate these findings using larger and more diverse samples to confirm the relationships between Diffusion of Innovation factors and internet access types. Additionally, future research should investigate the specific factors and mechanisms that drive the observed differences in perceptions and adoption behaviors across different internet access types.

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