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ARTICLE

How Does Traceability Adoption Affect Farm Performance in Lotus Production in Central Vietnam?

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ABSTRACT

This study investigates the impact of traceability adoption on farm performance in Vietnam's lotus value chain, focusing on revenue, productivity, and output price. The research endeavor employed stratified sampling, systematically dividing regions into districts and communities to obtain data on lotus cultivation in Central Vietnam. To assess the effect of traceability adoption on the performance of lotus farms, survey data from 363 respondents across central Vietnam were analyzed. The study employed propensity score matching (PSM) to evaluate the average treatment effect and mitigate the risk of selection bias. The results indicate that farmers who adopt traceability achieve higher revenue, productivity, and output prices than those who do not. In addition, the study's findings reveal several elements that may affect the decision to use traceability in lotus cultivation in Central Vietnam. The factors encompass the age of the household head, the quantity of plots designated for Lotus production, and the number of collectors involved. These findings underscore the importance of improving traceability in lotus production to facilitate sustained enhancements in the standard of living in central Vietnam. Enhancing the sector's sustainability and growth could be accomplished by promoting young involvement in lotus farming and increasing land accessibility for growers, supported by government initiatives.

Keywords: Traceability Adoption; Farm Performance; Lotus Production; Vietnam

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1. Introduction

The agricultural industry in Vietnam remains crucial to its economy, notwithstanding the nation's swift industrialization and economic diversification in recent decades [1]. In 2020, agriculture constituted 23% of Vietnam's GDP and employed more than 50% of its workforce, as the Vietnam General Statistics Office reported [2, 3]. This illustrates the sector's vital role in ensuring livelihoods and food security for a substantial population segment.

Farmers can promote the adoption of superior agricultural innovations to improve production, so augmenting both their own and the nation's food supply, ensuring food security, and promoting inclusive growth and poverty alleviation [1, 4]. Traceability is of utmost importance in diverse industries, such as agriculture, since it guarantees transparency, genuineness, and responsibility across the supply chain [5]. Supply chain management encompasses the surveillance and record-keeping of product transportation from its origin to the final consumer, offering crucial details regarding the product's trajectory, treatment, and quality [6]. Implementing traceability systems is crucial for improving food safety, safeguarding consumer health, and upholding brand integrity [7]. Nevertheless, the implementation of traceability systems in agriculture encounters obstacles, particularly in rural regions of developing nations, attributable to factors such as the structure of businesses, types of products, and market conditions [8].

Lack of awareness of the significance of food traceability, especially among small-scale food enterprises, impedes the adoption of traceability systems [9]. In agricultural traceability systems, the use of traditional centralized data storage methods can result in problems such as unequal access to information and decreased system efficiency [10]. The intricate nature of agricultural supply networks presents additional challenges in implementing efficient traceability systems [11]. Furthermore, the limited uptake of cutting-edge technology such as blockchain in agricultural and food supply chains, especially in poor countries, leads to low acceptance of traceability systems [12].

In response to these difficulties, previous studies have suggested inventive remedies, such as traceability systems based on blockchain technology [13]. Blockchain technology has advantages such as enhanced traceability, increased transparency, integration with Internet of Things (IoT) devices, and efficient support for food recalls [14]. Through the utilization of blockchain technology, agri-food supply chains can attain complete traceability, guaranteeing the reliability and genuineness of system information throughout all entities involved in the supply chain.

In general, traceability adoption in agricultural production is a multifaceted concept that enhances transparency, product quality, and market access by enabling the tracking and verification of agricultural products throughout the supply chain [5, 15]. While traceability adoption has been shown to improve farm performance by boosting product safety and expanding market opportunities [16, 17], its implementation poses significant challenges. High costs, complex compliance requirements, and limited technical capacity—especially among smallholder farmers—can negatively impact operations [18, 19]. These challenges make the relationship between traceability adoption and farm performance complex and sometimes contradictory. Therefore, This research is necessary to explore this relationship in different contexts, such as Lotus production, to address existing knowledge gaps and offer insights into how traceability can be effectively integrated to improve farm welfare and sustainability.

Lotus farming is a prevalent activity globally, with substantial production in countries including India, China, Japan, South Korea, Southeast Asia, Russia, and certain African states. In these places, lotus plants are typically cultivated for food, pharmaceutical, or ornamental uses, whereas in European and American countries, they are largely grown for ornamental reasons [20]. Nevertheless, full global statistical statistics regarding the farmed areas of lotus plants remain unavailable. In Vietnam, lotus plants have become a novel commodity in the food sector, alongside established commodities such as peanuts, soy, coffee, rubber, tea, cashews, and pepper. In Thua Thien Hue Province, the area dedicated to lotus cultivation rose consistently from 372.9 hectares in 2017 to 638.9 hectares in 2020. The expansion is predominantly focused on Phong Dien, Phu

Vang, Huong Tra, and Quang Dien districts. This expansion corresponds with a strategic transition in crop patterns, reducing sole dependence on rice farming and optimizing the use of existing land resources, such as fallow water surfaces, ponds, lakes, and low-lying paddy fields. The economic potential of lotus arises from its varied use in medicinal, cosmetics, culinary uses, and décor. Various components of the lotus plant, such as seeds, leaves, buds, and roots, provide benefits in medicinal herbs, cosmetics, and everyday dietary intake. Seeds generate roasted seeds, milk, tea, and wine. The cultivation procedure is uncomplicated and demands minimal maintenance, resulting in substantial growth in lotus cultivation. Retail prices fluctuate between 30,000 and 60,000 VND/kg, exceeding rice costs by four to six times. The cultivation of superior lotus cultivars for seed production may augment the economic worth of these plants. Lotus goods, particularly seeds, are widely utilized in culinary and health-related applications, both nationally and globally. Although lotus farming contributes to rural income, it has not yet completely achieved its potential [21].

This study aims to examine the correlation between traceability adoption and farm performance indicators, including revenue, productivity, and output price. The study's findings may be significant for enhancing traceability implementation in agricultural production. The findings are crucial not only for Vietnam but also for underdeveloped nations with poor traceability adoption. A study on the impact of traceability adoption on farm performance in lotus production in Vietnam is significant as it elucidates the intricate relationship between traceability implementation and farm productivity within smallholder agriculture, while also offering insights into strategies for enhancing agricultural resilience. The findings of this study can be utilized to build effective strategies for enhancing farmers' lives in lotus production, applicable not only in Vietnam but also in other developing countries.

This study identifies the correlation between traceability adoption and farm performance indicators, including revenue, productivity, and output price in lotus production, representing a novel finding in Vietnam. The results may apply to Vietnam and other developing nations with low levels of traceability adoption. Utilizing Propensity Score Matching (PSM) to mitigate selection bias in the estimating process reveals that farms adopting traceability achieve higher income, productivity, and output prices compared to their counterparts. The outcome elucidates the innovation and contribution to the correlation between traceability adoption and farm performance in lotus cultivation.

2. Materials and Methods

2.1. Data Source

This study employed a stratified sampling approach, meticulously dividing regions into districts, and communities for data collection for lotus production in Central Vietnam. The interviews were conducted strategically in critical locations along the lotus production process, specifically in Hue City and in Phong Hien and Phong An communes of Phong Dien district in Thua Thien Hue Province in central Vietnam. The selected study regions and participants for the research on the effect of traceability adoption on lotus farm performance in Central Vietnam were determined to guarantee relevance, representativeness, practicality, diversity, and ethical considerations. After discussing with the key farmers in lotus production in those regions, the study invited 363 lotus farmers to participate in the survey in 2023. Due to missing information in some variables, the sample of 360 producers was used for further analysis.

The intentional choice of these particular locations and events was to obtain a thorough perspective and intricate understanding of the dynamics surrounding lotus production, trade, consumption, and the regulatory framework. Numerous essential procedures are consistently executed during the preparation and purification of data for a study on the impact of traceability adoption on lotus crop performance in Central Vietnam. This encompasses imputation methods for missing data, identification, and elimination of outliers to enhance dataset integrity, normalization of data for uniform scaling, encoding of categorical variables, and data cleansing.

The questionnaires encompassed several subjects, such as lotus cultivation, trading methodologies, contacts between producers and traders, consumer behaviors, regulatory concerns, technical advancements, and the supportive ecology that fosters lotus value chains.

2.2. Variable Selection

In this study, various variables are used as control variables to estimate the effect of traceability adoption on farm performance in lotus production. All control variables are based on the literature review from previous research [15–21]. The household head's age and educational level have a considerable influence on the use of traceability systems in agricultural activities. According to research, elder household heads have greater experience, which can influence their decisions about technology use. Previous studies indicate that age may correlate with heightened adoption rates, attributable to acquired experience and understanding of agricultural operations [15, 16]. Furthermore, educated household heads tend to be more amenable to new technologies and practices, since they typically possess superior analytical abilities and an enhanced capacity to understand intricate information about traceability systems [22–25]. Therefore, the age and educational level of household heads are added to the estimation model as control variables to estimate the effect of traceability adoption on farmer performance in lotus production.

Social variables such as cooperative membership and community support influence traceability adoption. Farmers who belong to cooperatives are more likely to use safe production techniques, such as traceability, because these groups share resources and information [26]. Furthermore, analyzes how social networks and community perceptions influence farmers' decisions to use national traceability platforms [27, 28]. Family members, as key social networks, play a crucial role in shaping farmers' willingness to engage in traceability systems. In this study, we use variables such as the number of family members and the number of family laborers in the estimation model because the increase in those variables can be considered an increase in social networks. In addition, the economic incentives related to traceability adoption are intricately connected to the attributes of the land utilized for agricultural production. A previous study demonstrates that site factors, which affect production quality and safety, can directly influence the economic justification for implementing traceability [17, 21]. Consequently, other variables, including the total area of Lotus production and the total area of agricultural land, are incorporated into the estimation model. Furthermore, effective post-harvest management practices are essential for the successful implementation of traceability systems [29]. In addition, policy support and regulation are essential in affecting the adoption of traceability systems, especially in small and micro firms [30]. This indicates that in supply chains with numerous collectors, the intricacy of regulatory compliance may escalate, thereby influencing the decision to implement traceability solutions (**Table 1**).

2.3. Methodology

The objective of this study is to assess the adoption of traceability for lotus products on household welfare such as household income, productivity, and output price. Our specific goal is to compute the Average Treatment Effect on the Treated (ATT). To accurately assess the true influence of the adoption of traceability, it is necessary to compare the results achieved by households with the adoption of traceability with those achieved by those without adoption. The difficulty resides in the inability to directly see outcomes without the adoption of traceability, which is referred to as the counterfactual. Therefore, the objective of this work is to address this problem.

When doing impact evaluation, it is essential to carefully choose a control group that does not have any adoption of traceability to ensure a legitimate comparison. Although randomized experimental designs often include comparing outcomes between treatment and control groups, our investigation does not incorporate random assignment. The adoption of traceability is determined by individual preference, which might introduce self-selection bias. In the absence of empirical evidence, non-experimental techniques such as Instrumental Variable (IV), Propensity Score Matching (PSM), Difference-in-Differences (DID), or a combination of PSM and DID are crucial for assessing the Average Treatment Effect on the Treated (ATT) [31].

Instrumental Variables (IVs) are frequently employed to address selection bias resulting from unob-

Table 1. Summary statistics.

Variable	Mean	Std. Dev.	Min	Max
Revenue (1,000,000 VND)	63.285	64.315	1.4	576
Productivity (kg/hectares)	1.667	1.363	0.04	9.6
The output price (1000 VND/1 kg)	36.875	7.112	30	75
Traceability adoption (1: adoption; 0: Non-adoption)	0.025	0.156	0	1
Age of household head (Years)	57.742	9.111	35	77
Educational level of household head (Years)	7.342	3.025	0	12
Number of family members	5.175	1.771	2	10
Number of family labor	3.075	1.621	1	7
Total area of lotus production (m^2)	11.568	15.715	2	150
Number of plots for Lotus production	1.883	1.044	1	5
Total area of agricultural land (m^2)	11.284	15.784	1.5	150
Preliminary processing of products after harvest (1: Yes; 0: No)	0.358	0.480	0	1
Number of collectors	1.300	0.793	0	3

Note: 1 USD = 25.000 VND.

servable factors. For IV (instrumental variable) to have a significant impact, it should be associated with the ability to obtain the adoption, but it should not directly determine the consequences. Nevertheless, the task of locating a dependable IV is arduous and might lead to biased results if executed improperly. Considering this, we choose Propensity Score Matching (PSM) as a more appropriate approach to tackle selection bias.

PSM involves initially evaluating the probability of households having the adoption of traceability using a logit model, taking into account certain covariates. This calculation produces a propensity score for both the treated group (those who have the adoption of traceability) and the control group (those who have not the adoption of traceability). The logit model is expressed as:

$$P(X) = \text{logit}(D = 1) = \alpha + \beta X$$

Where the variable D represents the treatment status, which indicates whether or not the adoption of traceability. The variable X includes observable properties that are not influenced by this therapy.

Before implementing matching, it is imperative to satisfy two crucial conditions. Initially, it is imperative to define the shared support region, encompassing the range of propensity score values where both the treated (adoption) and control (non-adoption) groups coexist. To address situations when a particular household in the adoption group does not have a corresponding match in the non-adoption group, individuals with propensity scores that exceed the maximum or fall below the minimum of the non-adoption scores are excluded. By utilizing this approach, we ensure that only residences situated within the common support zone are used for matching, hence preventing biased comparisons between families that are not comparable. By implementing common support constraints, the estimates become more robust and the quality of the matches improves by reducing unfavorable matches.

The second criterion involves satisfying the balancing property test[32], which asserts that observations with the same propensity scores should exhibit the same distribution of observable qualities (X variables), regardless of their access status. There is a lack of recognized criteria for defining acceptable degrees of imbalance in propensity scores. It is commonly advised that the maximum standardized difference for specific factors should ideally range from 10% to 25%.

In the last stage, access is matched with non-adoption based on similar inclinations. The formula for calculating the average treatment effect on the treated (ATT) using the propensity score matching (PSM) estimator, as outlined by Becker and Ichino (2002), is as follows:

$$\text{ATTPSM} = E(Y_{iA}|D = 1, P(X)) - E(Y_{iN}|D = 0, P(X)) \quad (1)$$

where ATT in Equation (1) measures the effect of the adoption of traceability on the observed outcomes of adoption such as household income, productivity, and output price. D denotes the treatment (the adoption of traceability) status of the household. Y_{iA} and Y_{iN} are ATT measures of the effect of the adoption of traceability on the observed outcomes of the adoption, X is a vector of the observed characteristics, P(X) denotes the propensity score of each household given the observed covariates, and ATTPSM is the difference in outcomes between the adoption and non-adoption appropriately matched by the propensity score P(X).

3. Results

Table 2 displays the summary statistics of the chosen farm characteristics utilized in the duration model and the balancing tests conducted for each covariate before (unmatched) and after matching (matched). The unpaired sample demonstrates statistically significant disparities in the means of two covariates (the Age of the Household Head and multiple plots for Lotus production) between the treatment and control groups. If there is a correlation between these factors and the decision to embrace traceability, it will result in a distorted estimation of the impact of traceability adoption on household welfare. Following the matching process, most of the covariate means between the treatment and control groups show no significant statistical differences. The results demonstrate that the covariates are considerably better balanced following the matching process, reducing endogeneity's impact on the decision to implement traceability.

Table 2. Balance tests comparing unmatched and matched samples.

Variables	Unmatched			Matched		
	Treatment	Control	p-Value	Treatment	Control	p-Value
Age of Household Head	52.333	57.880	0.071	52.333	55.667	0.533
Educational level of household head	8.000	7.325	0.509	8.000	9.000	0.290
Number of family members	5.667	5.162	0.400	5.667	6.333	0.245
Number of family labor	3.333	3.068	0.629	3.333	3.000	0.461
Total Area of lotus production	14.667	11.488	0.550	14.667	18.667	0.409
Number of plots for lotus production	3.333	1.846	0.000	3.333	4.000	0.150
Total area of agricultural land	14.000	11.215	0.602	14.000	18.667	0.325
Preliminary processing of products after harvest	0.333	0.359	0.875	0.333	0.667	0.176
Number of collectors	1.000	1.308	0.251	1.000	1.000	0.126

Source: Author's Calculations.

Figure 1 illustrates the distribution of propensity scores for the adoption and non-adoption of traceability before and after matching. In the unmatched (**a**), there is a clear imbalance between the two groups, with the "Non-adoption of Traceability" group exhibiting a much higher density at lower propensity scores, indicating significant differences in characteristics between adopters and non-adopters. After applying the matching process, the matched (**b**) displays a more balanced distribution, as the density curves of the two groups become more comparable. This improved alignment suggests that matching successfully reduced selection bias, ensuring a more reliable comparison of the effects of traceability adoption.

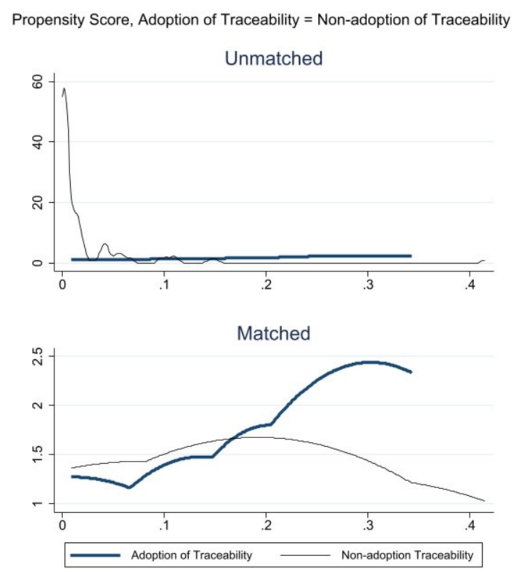

Figure 1. Distribution of Propensity Scores before and after matching (**a**) Unmatched (**b**) Matched.

Table 3 presents the factors linked to the traceability adoption of farmers in lotus production by the Logit Estimation. The links are illustrated using a logit estimation model that incorporates marginal effects.

The propensity to embrace traceability in lotus production differs throughout various age cohorts, with younger individuals exhibiting a greater predisposition towards traceability systems. The result of the estimation shows that as the age of the household head increases, the probability of traceability adoption for lotus production decreases by 0.3%. This pattern aligns with the results of other studies that have examined the implementation of traceability systems across various industries since some previous research indicated that the probability of adopting traceability for agricultural production decreases as the age of household heads increases [26, 27].

In addition, the study shows the land fragmentation index such as the number of plots that have a positive effect on the adoption traceability in Lotus production. The marginal coefficient is 0.046 with a significant level of 5%. Land fragmentation can greatly influence agricultural practices, especially by promoting the adoption of traceability systems among farm households. Land fragmentation, characterized by farmers owning many smaller parcels of land scattered across different areas, can give rise to several issues including heightened expenses, inefficient use of resources, and decreased productivity due to the need to manage disparate land parcels [28, 29]. The presence of inefficiencies in farm operations can lead to decreased profitability, motivating farmers to search for solutions to enhance the efficiency of their agricultural activities. Furthermore, research has shown that land fragmentation can lead to a rise in adverse external effects, elevated expenses, and a heightened likelihood of conflicts among nearby farmers [33]. These problems highlight the significance of establishing enhanced management techniques, such as the deployment of traceability technologies. These systems can optimize operations, improve transparency, and reduce the negative impacts of fragmented land ownership [34].

Table 4 indicates the cause-and-effect relationships between traceability adoption and household welfare in lotus production. Propensity score matching (PSM) was used to mitigate selection bias, and the impact of adoption or non-adoption on household welfare was assessed. After matching, some calculations were modified with the Propensity Score Matching (PSM) method, particularly concerning the impacts of traceability adoption on household welfare such as revenue, productivity, and output price in lotus production.

After using the PSM program, the group that adopted traceability received more revenue, productivity, and output price than the other. The difference between these two groups was statistically significant, with a p-value of 5%.

4. Discussion

This study seeks to elucidate the ambiguous relationship between traceability adoption and household performance in lotus cultivation in Central Vietnam. The study used propensity score matching to reduce the selection bias since estimating the effect of traceability adoption on farm performance in lotus production in Central Vietnam. The results reveal that lotus farms that use traceability generate greater revenue, productivity, and output price than others [17, 35, 36]. This can be explained by farms implementing traceability producing greater income due to enhanced consumer trust, access to premium markets, or the capacity to charge higher prices for their products because customers and buyers are guaranteed quality and authenticity. In addition, farms with traceability systems are more productive, most likely because traceability helps streamline processes. Farmers who measure and monitor many production areas may be able to uncover inefficiencies, decrease waste, and better manage resources. Furthermore, traceability may enable farmers to charge more for their lotus products. This could be due to improved quality control or certification, making their products more appealing to customers who value transparency and safety. The result of this study is linked to the previous research that indicates that the adoption of traceability positively affects firm revenue and traceability acts as a quality assurance mechanism that can enhance market performance [28, 37].

In addition, several household characteristics and farm characteristics influence the adoption of traceability in lotus production, as estimated by a logit model. A negative correlation is observed between the household head's age and the likelihood of implementing traceability systems. This finding aligns with previous research indicating that older household heads are less

Table 3. Factor linked to the adoption of Traceability for Lotus production (Logit Model).

Variables	Coefficient	P-Value	Marginal Effect	P-Value
The Age of Household Head	−0.131**	0.022	−0.003***	0.006
The educational level of the Household head	−0.016	0.763	0.000	0.769
The number of family members	−0.131	0.693	−0.003	0.672
The Number of Family labor	0.131	0.692	0.003	0.671
Total Area of Lotus Production	−0.192	0.202	−0.004	0.138
Number of plots for Lotus production	2.224***	0.000	0.046***	0.000
The total area of Agricultural Land	0.008	0.948	0.000	0.947
Preliminary processing of products after harvest	−0.821	0.594	−0.017	0.557
The number of Collector	−1.296**	0.040	−0.027**	0.011
Constant	1.994	0.563	-	-

*** p < 0.01, ** p < 0.05, * p < 0.1.
Source: Author's Calculations.

Table 4. Effect of traceability adoption in household welfare.

VARIABLES	Revenue Coef.	Productivity Coef.	Output Price Coef.
Adoption traceability (Yes = 1; Otherwise, = 0) - Matched	31.315** (15.442)	0. 759** (0.364)	0.333** (1.630)
Observations	360	360	360

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1.
Source: Author's Calculations.

inclined to use traceability systems [30]. In contrast, the number of plots dedicated to lotus cultivation shows a significant positive relationship with the use of traceability. This indicates that farmers managing multiple plots are more likely to adopt traceability methods. This observation is consistent with studies suggesting that the size and complexity of a farm can facilitate the use of traceability systems [38]. Additionally, the involvement of collectors in the supply chain negatively impacts the implementation of traceability systems. This suggests that increased engagement among collectors may deter farmers from adopting traceability methods, a situation that can be linked to the complexities and potential conflicts arising from multiple intermediaries within the supply chain [39]. Other factors, such as the household head's education level, family size, family labor, total lotus cultivation area, total agricultural land area, and initial processing steps post-harvest, do not significantly affect the adoption of traceability systems in this context. This finding mirrors conclusions from other studies that suggest certain socioeconomic factors have a minimal impact on the speed of agricultural technology adoption [40, 41].

5. Conclusions

Lotus production is considered an effective strategy for transforming livelihoods in rural Vietnam, such as Central Vietnam. Low-quality land encourages farmers to transfer from main production, such as rice or maize, to lotus production to ensure household livelihood and food security in Central Vietnam. The findings indicate that the implementation of traceability can enhance farm performance, resulting in increased income, productivity, and output prices compared to alternatives.

Based on these findings, actions might be implemented to enhance the importance of traceability adoption in the performance of lotus cultivation in rural Vietnam. Several strategic activities can be taken to increase the importance of traceability adoption in lotus farming performance in rural Vietnam, particularly in light of the socioeconomic factors identified as impacting adoption. The negative relationship between the age of the household head and the chance of adopting traceability systems shows that younger farmers are more open to new technology. Encouraging young farmers to participate in lotus production can lead to increased adoption of traceability due to their understanding of its benefits. Furthermore, teaching elder farmers about the benefits of traceability adoption may inspire them to implement more traceability [42]. Furthermore, the positive relationship between the number of plots allocated to lotus production and traceability adoption suggests that farmers who manage several plots are more inclined to use these systems. This shows that cooperative approaches could be useful for enhancing traceability. By encouraging farmers to create cooperatives, they may share resources, knowledge, and technology, enhancing the overall capacity for traceability implementation. Such cooperatives can also help with collective marketing techniques that emphasize traceability, thereby increasing market access and consumer trust [43].

Despite the novel discoveries in our work, certain limitations persist that require enhancement in subsequent research. Standard Propensity Score Matching (PSM) utilizing cross-sectional data may only account for selection based on reported factors, failing to address unobserved variability that may influence adoption and outcomes. Utilizing panel data, an alternative approach can account for time-invariant unobserved heterogeneity when estimating the causal relationship between traceability adoption and household performance, including revenue, productivity, and output prices in agricultural production in Vietnam.

Author Contributions

Conceptualization, N.T.P. and N.D.K.; methodology, N.T.P., N.D.K., L.T.A., and N.C.D.; software, N.T.P., N.D.K., and P.X.H.; formal analysis, N.T.P., N.D.K., N.C.D.; writing—original draft preparation, N.T.P., N.D.K., N.C.D., L.T.A., and P.X.H.; writing—review and editing, N.T.P. and N.D.K. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not applicable.

Data Availability Statement

Data is available upon request from the author.

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Conflicts of Interest

The authors declare no conflict of interest.

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