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RESEARCH ARTICLE

Trade, Foreign Direct Investment and Agriculture in Developing Countries

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Abstract: Agriculture continues to make significant contributions to developing countries in the presence of globalisation. Thus, international trade and foreign capital flows are important to developing countries. The authors used data on 115 developing countries from 1995 to 2020 to investigate the effect of inward and outward foreign direct investment (FDI) on trade in the agricultural sector of developing countries. Inward FDI enhanced exports, imports, and trade openness. However, outward FDI did not affect exports, imports, and trade openness. To escalate international trade in agricultural products, developing countries must continue to promote the inflow of FDI into agriculture (*AIFDI*). This requires paying attention to appropriate management of the macroeconomy, keeping down the inflation rate, optimising the currency exchange rate, and keeping interest rates down to boost investment among others. Whilst these would enhance *AIFDI* that would promote trade, these would directly promote trade. As developing countries have often suffered foreign exchange pressures, they must enhance foreign exchange receipts through increased exports. Increasing human capital can increase exports. Unlike existing studies, the authors used more current data covering many developing countries and accounted for endogeneity.

Keywords: Agricultural exports; Agricultural imports; Agricultural trade openness; Capital flow; Foreign capital

1. Introduction

Agriculture can contribute to ending severe impoverishment, encourage shared wealth, and feed a projected 9.7 billion people by 2050 [1]. Progress in the agriculture sector is between two to four times more useful in growing incomes among the most impoverished relative to other sectors [1]. Further, agriculture is also essential to economic progress: representing 4% of global gross domestic product

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(GDP) and exceeding 25% of GDP in some developing countries. As global investment needs are in the range of $5 trillion to $7 trillion per year, the estimates for investment needs in developing countries are between $3.3 trillion and $4.5 trillion per year [2,3]. The developing countries would require foreign investments to meet this need.

Foreign direct investment (FDI) is an investment made by an occupant firm in one economy to find a long-term interest in a firm that is a denizen in another economy. The long-term interest infers the presence of a lasting relationship between the direct investor and the direct investment firm and a significant degree of influence on the leadership of the firm. The basis of the long-term relationship is the control of 10% or more of the firm by a direct investor [4-8]. Under the directional principle, direct investment is shown as either direct investment abroad (outward, OFDI) or direct investment in the reporting economy (inward, IFDI) [4,8]. Developing countries have pursued varied policies to attract FDI into their respective agricultural sector to stimulate local investment and supply of funds, increase export capacity, increase employment, and enhance technology transfer [2,9-13]. Regarding exports, Aihu and Chedjou [14], Harding and Javorcik [15] and Kang [16] did find that IFDI promotes exports for the total economy and the manufacturing sector. For imports, whilst Aihu and Chedjou [14] reported a positive effect of IFDI, Djokoto [17] and Latif and Younis [18] found a neutral effect. The effects of IFDI on trade openness are most inconsistent; Aihu and Chedjou [14], Karaca, Güney, and Hopoğlu [19] and Yaoxing [20] found a positive effect, Umar, Chaudhry, Faheem, and Farooq [21] found a negative effect for lower-income and lower-middle-income countries, but the neutral effect for upper middle-income countries. Although developing countries are generally net recipients of capital flows [22-27], Sun and Zhang [28] found trade openness enhances the effect of OFDI from China. Considering these inconsistencies, what is the effect of FDI on trade in the agriculture sector in developing countries?

Existing studies on FDI and trade nexus have focused on the total economy [19,23]. Harding and Javorcik [15] and Kang [16] addressed manufacturing, only Djokoto [17] and Latif and Younis [18] studied agriculture. Whilst Djokoto [17] studied a single country, Latif and Younis [18] studied four countries with data from 1995 to 2017. Some limitations emerge especially, regarding agricultural studies. First, the dependent variable in the agriculture studies has been exports and imports and not trade openness, a more inclusive measure of trade. Second, the number of developing countries covered is limited, thus, the results of the studies cannot be generalised for developing countries. Third, although, the data used were current at the time, these are not the most current now. Fourth, the studies did not account for endogeneity. This could have led to the correlation of the error term with some of the explanatory variables thereby violating an assumption of undergirding ordinary least squares. This could cause an inaccurate effect of FDI on trade. Finally, the analyses ignored the role of OFDI, the counterpart of IFDI, which also affects trade. This could result in omitted variable bias. We make up for these limitations as follows. Firstly, in addition to exports and imports, we assessed the effect of FDI on trade openness. Secondly, we covered 115 developing countries in Africa, Latin America and the Caribbean, Asia, and the Pacific. Thirdly, we used data from 1995 to 2020. In the fourth place, we took account of endogeneity in macroeconomic variables and finally, included OFDI in our model.

Inward foreign direct investment enhanced exports, imports, and trade openness. To escalate international trade in agricultural products, developing countries must continue to promote the inflow of FDI into agriculture (*AIFDI*). This requires paying attention to appropriate management of the macro economy; keeping down the inflation rate, optimising the currency exchange rate, and keeping interest rates down to boost investment among others. Whilst these would enhance *AIFDI* that would promote trade, these would directly promote trade. As developing countries have often suffered foreign exchange pressures, they must enhance foreign exchange receipts through increased exports. Increasing human capital can increase exports.

In what follows, we present the theories of trade and cross-border capital flows. We examined the pertinent literature on developing countries to assess the scope of knowledge on the title of the study, assess the differences and similarities among them and provide the information needed for the discussion section. In Section 3, the modelling is presented with a description of the data and estimation procedures. The results of the estimation are reported, and these are explained considering the relevant literature in Section 4. In the final section, we conclude the study with some policy recommendations.

2. Literature Review

2.1 Theoretical Review

The workhorse theory about trade and capital flows is the Hecksher-Ohlin framework [29,30]. In this framework, trade and capital flows are perfect substitutes under a two-country, two-factor model and two-commodity. This condition is sufficient to ensure factor price equilibrium and this equilibrium is adequate to guarantee commodity price equilibrium. Mundell [26] states, '….the ability to engage in commodity trade can eliminate the need for capital to flow from the capital-abundant countries to the capital-scarce countries since the rate of return differences can be eliminated through trade alone'. In acknowledging the factor substitutability of FDI and trade, Mundell [31] noted that increasing trade restrictions enhances factor movements, and an increasing restriction to factors enhances trade. Notwithstanding the significant role of the Hecksher-Ohlin-Mundell framework in explaining trade and capital flows, it is constrained in its ability to provide a complete analysis of trade and capital flows and their collaboration under a rich set of circumstances. Specifically, capital mobility in the static two-country, two-factor, two-commodity framework is restricted to the apportionment of capital across countries, for a fixed level of world capital stock [26].

Despite the Hecksher-Ohlin-Mundell position of substitutability between trade and capital flows, Antras and Caballero [32] have however, shown the complementarity between trade and capital flows when relative advantages across countries are not decided only by factor endowments, but also by financial conglomeration.

2.2 Empirical Review

These theories have informed the developing country literature on the effects of FDI on trade that addressed agriculture [17,18], manufacturing [15,16], and the total economy [14,19-21,28,33]. The geographies included China [28], Cote d'Ivoire [20], Ghana [17], Jordan, Morocco, Egypt, and Thailand [18], BRICS-T [19], Africa [14], and developing countries [15,21]. Djokoto [17], Karaca et al. [19] and Yaoxing [20] employed Granger causality, Sun and Zhang [28], and Umar et al. [28] employed fixed effects, random effects, and general method of moments. Harding and Javorcik [15] applied the difference-in-difference method.

Inward FDI was positively related to trade openness [14,19,20]. However, Umar et al. [21] found a negative relationship for lower income (LIC) and lower-middle-income countries (LMIC) but a neutral effect for upper-middle-income countries (UMIC). Harding and Javorcik [15] reported a positive effect of FDI presence on exports of developing countries. The effect was stronger for developing countries than for developed countries. "A weaker and quantitatively smaller effect for developed countries is consistent with the view that foreign presence is closing a technology gap. For a developed economy, there is less of a technology gap to close, and the foreign presence has a minor effect on the unit values of exports." [15]. Aihu and Chedjou [14] reported positive effects of inward FDI on exports and imports in the total economies of Africa. Kang [16] found a positive effect of FDI on Korean manufactured exports to developing but a negative effect on manufactured exports to developed countries. In the only study that investigated the role of outward FDI (OFDI) on trade, Sun and Zhang [28] found a positive effect of China's OFDI on Belt and Road countries on trade in China.

The effect of population growth on trade openness was positive [19,34,28] but Osei et al. [33] found a neutral effect for LIC and LMIC. The effects of GDP growth on trade openness have been mixed. A positive effect [19,15,28,21]. Osei et al. [33] reported a positive effect for lower-income countries and a negative effect for lower-middle-income countries. Mbogela [34] matched the negative effect with evidence on African countries. Aihu and Chedjou [14] however, reported a neural effect on exports, imports, and trade openness. As in the case of GDP growth, the effect of population growth is also mixed. Whilst Osei et al. [33] did not find a significant effect of population growth on trade openness, Harding and Javorcik [15] found a negative effect on exports whilst Karaca et al. [19], Mbogela [34] and Sun and Zhang [28] found a positive effect of population growth on trade openness.

Mbogela [34] measured trade policy as the freedom to trade internationally and found that the variable did not significantly influence trade openness in Africa. However, Umar et al. [21] reported a positive effect on trade openness. Whilst the effect of inflation and domestic investment had a positive effect on trade openness, the effect of human capital was mixed; negative for lower-income countries [21], and neutral for lower-middle-income countries [21].

Djokoto [17] and Latif and Younis [18] are specific agricultural papers on FDI-trade nexus. In the only agricultural FDI-trade nexus paper, Djokoto [17] investigated the effect of FDI inflow on imports and exports in Ghana. Using Granger's instantaneous causality approach with data from 1961 to 2008, FDI substituted imports whilst FDI did not have a discernible effect on exports in the short-run. In the long run, imports and FDI complemented each other. Djokoto [17] explained that MNEs would need to import some capital items and raw from abroad including from parent companies. To some extent, employees of foreign firms would generally prefer goods from their home country that could drive up imports of finished goods. Latif and Younis [18] studied Jordan, Morocco, Egypt, and Thailand collectively using data from 1995 to 2017. Whilst FDI promoted net exports, exports and imports were not significantly affected by FDI.

It would be observed that the studies that investigated the effect of FDI on trade used FDI inflow, not FDI outflow except Sun and Zhang [28]. Although the two studies focused on agriculture, attention was given to exports and imports and not trade openness. Moreover, the analysis did not consider other variables that explain exports and imports. We fill these gaps by investigating the effect of inward and outward FDI on exports, imports, and trade openness in agriculture in developing countries.

3. Data and Methods

3.1 Models and Data

Congruent to the literature on FDI and trade [14,33-35], we specify Equations (1)-(3).

$$AEX_{it} = \alpha_0 + \alpha_1 AIFDI_{it} + \alpha_2 AOFDI_{it} + \alpha_3 AINV_{it} + \alpha_4 AGDPG_{it} + \alpha_5 EXRATE_{it} + \alpha_6 FTTRADE_{it} + \alpha_7 HC_{it} + \alpha_8 INFLA_{it} + \alpha_9 POPG_{it} + \omega_{it} \quad (1)$$

$$AIM_{it} = \beta_0 + \beta_1 AIFDI_{it} + \beta_2 AOFDI_{it} + \beta_3 AINV_{it} + \beta_4 AGDPG_{it} + \beta_5 EXRATE_{it} + \beta_6 FTTRADE_{it} + \beta_7 HC_{it} + \beta_8 INFLA_{it} + \beta_9 POPG_{it} + \varphi_{it} \quad (2)$$

$$ATO_{it} = \gamma_0 + \gamma_1 AIFDI_{it} + \gamma_2 AOFDI_{it} + \gamma_3 AINV_{it} + \gamma_4 AGDPG_{it} + \gamma_5 EXRATE_{it} + \gamma_6 FTTRADE_{it} + \gamma_7 HC_{it} + \gamma_8 INFLA_{it} + \gamma_9 POPG_{it} + \tau_{it} \quad (3)$$

There are *i* developing countries and *t* years. The α, β and γ are parameters to be estimated. The ω, φ and τ are idiosyncratic error terms. Agricultural export (*AEX*) is the ratio of agricultural exports to agricultural value added. Agricultural import (*AIM*) is the ratio of agricultural imports to agricultural value added. The sum of *AEX* and *AIM* is agricultural trade openness (*ATO*). *AEX*, *AIM,* and *ATO* constitute measures of *TRADE*. Anderson [36], de Azevedo et al. [37], Djokoto [2,10,38,39], Kastratović [40], Narteh-Yoe, Djokoto and Pomeyie [41] and Osei, et al. [33] measured trade similarly. The inflow of FDI into agriculture in developing countries is *AIFDI*, measured as the ratio of FDI to agricultural value added. We measured *AOFDI* = 1 for observation of the outflow of FDI into agriculture and 0 otherwise. This is outward FDI out of agriculture in developing countries. The use of the dummy variable was necessitated by limited non-zero values reported for agricultural OFDI at the source. *AINV* is agricultural domestic investment measured as the ratio of agricultural gross fixed capital formation to agricultural value added [2,10,39,42]. We defined *AGDPG* as the annual growth rate of agricultural value at 2015 prices. Growth of the agricultural sector can absorb agricultural imports through the consumption of agricultural inputs and agricultural products as raw and intermediate goods for processing. Agricultural exports would be acquired from domestic agricultural production resulting from increased *AGDPG*.

The rest of the variables are not specific to the agricultural sector. The official exchange rate *EXRATE* is measured as the annual average of the number of the developing country's currency per US$ 1. A high *EXRATE* would raise the prices of agricultural imports and could dampen agricultural imports whilst promoting agricultural exports. Agricultural produce exporters would expect more revenue denominated in the domestic currency. Umar et al. [21] reported the effect of the exchange rate on agricultural trade. We define *FTTRADE* as the freedom to trade internationally [34]. *FTTRADE* is a composite measure of the absence of tariff and non-tariff barriers that affect imports and exports of goods and services. This is composed of the trade-weighted average tariff rate and non-tariff barriers. The weighted average tariff uses weights for each tariff based on the share of imports for each good. A low *FTTRADE* means a low prospect to trade than a high *FTTRADE*. Whilst the former would discourage *TRADE* [34] the latter would enhance international trade (*TRADE*). *HC* is human capital, defined as secondary school enrolment percent of gross enrolment. High *HC* contributes to high employment in the production of goods and services that can be exported. *HC* can be combined with imported goods to produce for domestic and the export market. *HC* has a relationship with trade [21,43,44]. *INFLA*, inflation, is measured as the annual growth rate of the consumer price index. High *INFLA* reduces the value of the developing country's currency. This could discourage imports as well as exports. However, Osei et al. [33] found that *INFLA* does not depress trade. *POPG* is the annual growth rate of the population of males and females. A high population increases the market for the consumption of imports as well as increased labour for production for exports. Therefore, *POPG* could influence *TRADE* [19,34].

Data for the study comprised 115 developing countries (Appendix) from 1995 to 2020. Aside from the availability of data, the period also covers increased foreign direct investment activity in developing countries. Data on *AEM*, *AIM*, *AGDPG*, and *AINV* were obtained from FAOSTAT [45] whilst World Development Indicators of the World Bank [46] was the source of *EXRATE*, *HC*, *INFLA* and *POPG*, The Heritage Foundation [47] is the source for *FTTRADE*.

3.2 Estimation Procedure

The panel structure of the data (large cross-section than time series) necessitated the application of the estimation of fixed and random effects estimators. However, as macroeconomic variables could be plagued with endogeneity, we employed the general method of moments (GMM) to take care of the possible endogeneity. We used *xtdpdgmm* [50] to reduce the number of instruments.①

① We employed the Sargan test [51,52], to explore the overidentifying restrictions and the Arellano and Bond [48] test to test for the presence of second-order serial correlation.

4. Results and Discussion

4.1 Summary of the Data

The standard deviation of *ATO* is about two times that of *AIM* and close to three times that of *AEX* (Table 1). This suggests a larger spread of *ATO* than *AEX* and *AIM*. The mean of *AIFDI* is lower than its standard deviation suggesting over-dispersion of *AIFDI*. As *AOFDI* was defined as a dummy variable, the mean represents the percentage of observations with *AOFDI* as 1. Specifically, only 8% of the 2,462 observations recorded *AOFDI*. This small proportion is in line with the fact that outward FDI tended to originate more from developed countries than from developing countries and is underscored in the literature [22-27].

Table 1. Summary statistics.

Variable	Observation	Mean	Standard deviation	Minimum	Maximum
AEX	2,462	0.8113	5.2582	0	96.7905
AIM	2,462	1.4886	7.3732	0.0208	118.4649
ATO	2,462	2.2999	12.5249	0.0594	214.5246
AIFDI	2,462	0.0052	0.0327	–0.1076	0.8139
AOFDI	2,462	0.0804	0.2720	0	1
AINV	2,462	0.1010	0.0642	0.0089	0.4896
AGDPG	2,462	0.0299	0.0882	–0.7022	1.2342
EXRATE	2,454	1.26e+07	2.22e+08	0.0028	5.60e+09
FTTRADE	2,462	64.6789	15.0331	0	94.8000
HC	2,347	63.4170	29.9712	5.2834	212.5903
INFLA	2,460	11.2421	102.4682	–16.1173	4145.106
POPG	2,462	1.9142	1.3267	–16.8806	17.3991

4.2 Results

We estimated Equations (1)-(3) and performed robustness checks on the estimates of the key coefficients (Table 2). The sign of the coefficients of *AIFDI* are positive and the magnitudes are similar across models 1-9. Similarly, the coefficients of *AOFDI* are similar in magnitude across models 1-9. These suggest the estimates of *AIFDI* and *AOFDI* are robust to the control variables.

In the case of agricultural imports (*AIM*) as the dependent variable, the coefficients of *AIFDI* and *AOFDI* are similar across models 10-18 suggesting the robustness of the estimates of *AIFDI* and *AOFDI* (Table 3). For agricultural trade openness, *ATO*, as the dependent variable, the coefficients of *AIFDI* and *AOFDI* are also similar across models 19-27 suggesting the robustness of the key estimates (Table 4). It would be observed that the estimates of *AIFDI* in Table 4 are about two times the magnitude of those in Table 2 and more than those in Table 3. Also, across Tables 2-4, the coefficients of the lag of the dependent variable, are positive, statistically significant, and similar in magnitude. Whilst the statistical significance confirms that the endogeneity has been cared for, the similarity across models suggests the robustness of the estimates to control variables.

The complete models in Tables 2-4 are assembled in Table 5. The probability of the second-order serial correlations tests is invalidated signifying no second-order correlation in the errors of models. The probability of the Sargan-Hansen test also shows values above 10%. This implies that the over-identifying restrictions imposed in the estimation are valid. Following these impressive model properties, the panel model estimated is appropriate. Whilst the estimates of the coefficients in Table 5 are similar, across the models, the estimates in model 27 appear to be larger than those in models 9 and 18. This is not surprising as the dependent variable in model 27 (*ATO*) is the sum of the dependent variables in models 9 and 18 (*AEX* and *AIM*). The increased value of *ATO* resulted in higher coefficients than those in models 9 and 27.

4.3 Discussion of the Effects of Foreign Direct Investment on Trade

The coefficient of *AIFDI* of 0.6882 suggests a US$ 1 rise in agricultural inward FDI will raise exports by 69 cents (Table 5). Although this is inelastic, nevertheless, it shows that FDI in the agricultural sector of developing countries enhances trade. This can be attributable to multinational enterprises (MNEs) engaging in exports of their products to the parent company and other affiliates as well as non-affiliate customers outside the country. As many developing countries produce primary agricultural products, the exports to parent firms and other affiliates fit into the vertical integration of the MNEs. The export-enhancing role of *AIFDI*, *ceteris paribus* should improve the foreign exchange receipts of developing countries. Whilst the finding is contrary to the Hecksher-Ohlin-Mundell position of substitutability between trade and capital flows, it is consistent with the Antras and Caballero [32] position of complementarity of trade and capital flows. In the empirical space, our results conform to that of the manufacturing sector in developing countries [16] and the total economies of Africa [14]. But Djokoto [17] and Latif and Younis [18] reported a neutral effect of *AIFDI* on trade in Ghanaian agriculture and the agriculture of Jordan, Morocco, Egypt, and Thailand, respectively.

A US$ 1 increase in *AIFDI* will induce an 87 cents increase in imports. The investment codes of developing countries contain concessions on imports of raw materials

Table 2. Estimations and robustness checks for the effect of foreign direct investment on exports.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	*AEX*	*AEX*	*AEX*	*AEX*	*AEX*	*AEX*	*AEX*	*AEX*	*AEX*
L.AEX	1.0833*** (0.0004)	1.0518*** (0.0233)	1.0831*** (0.0004)	1.0832*** (0.0004)	1.0826*** (0.0010)	0.3494* (0.2103)	1.0836*** (0.0007)	1.0877*** (0.0037)	0.3633* (0.1950)
AIFDI	0.8699 (0.5739)	0.7516 (0.5086)	0.8467 (0.5978)	0.8647 (0.5741)	0.8596 (0.5645)	0.6825** (0.2847)	0.8699 (0.5753)	0.8488 (0.6238)	0.6882** (0.2855)
AOFDI	0.0576 (0.0370)	0.0216 (0.0724)	0.0591 (0.0387)	0.0482 (0.0345)	0.0543 (0.0358)	–0.0020 (0.0328)	0.0555 (0.0361)	0.0282 (0.0528)	–0.0047 (0.0372)
AINV		7.2822 (5.2882)							0.6663*** (0.2268)
AGDPG			–0.4083 (0.3494)						–0.1026*** (0.0348)
EXRATE				–0.0000*** (0.0000)					–2.41e-11 (1.65e-11)
FTTRADE					0.0018 (0.0019)				0.0005 (0.0006)
HC						0.0052*** (0.0016)			0.0046*** (0.0017)
INFLA							–0.0000 (0.0000)		1.42e-07 (5.59e-06)
POPG								0.1547 (0.1527)	0.0009 (0.0075)
CONSTANT	–0.0274*** (0.0056)	–0.6810 (0.4604)	–0.0157 (0.0152)	–0.0261*** (0.0055)	–0.1459 (0.1195)	–0.1105 (0.1099)	–0.0275*** (0.0055)	–0.3267 (0.2971)	–0.1823 (0.1237)
Model diagnostics									
Observations	2,347	2,347	2,347	2,340	2,347	2,239	2,346	2,347	2,235
Countries	114	114	114	114	114	113	114	114	113

1. Values in parenthesis are Windmeijer's (2005) finite-sample correction as the default two-step standard errors are biased in finite samples due to the neglected sampling error in the weighting matrix. 2. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. 3. All models estimated with GMM (xtdpdgmm in Stata) using the collapse option to control for instrument proliferation.

Table 3. Estimations and robustness checks for the effect of foreign direct investment on imports.

	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
VARIABLES	*AIM*	*AIM*	*AIM*	*AIM*	*AIM*	*AIM*	*AIM*	*AIM*	*AIM*
L.AIM	1.0212*** (0.0028)	0.9879*** (0.0247)	1.0210*** (0.0026)	1.0212*** (0.0028)	1.0211*** (0.0033)	1.0745*** (0.0103)	1.0212*** (0.0028)	1.0257*** (0.0026)	1.0736*** (0.0094)
AIFDI	0.3811 (0.6453)	0.3617 (0.5270)	0.3066 (0.6224)	0.3805 (0.6450)	0.3936 (0.6776)	1.2703** (0.6404)	0.3719 (0.6480)	0.1613 (0.6152)	0.8694* (0.4866)
AOFDI	0.0367 (0.0810)	–0.0502 (0.1681)	–0.0519 (0.1074)	0.0409 (0.0795)	0.0331 (0.1029)	–0.0673 (0.0679)	0.0347 (0.0856)	–0.0316 (0.0998)	–0.0215 (0.0732)
AINV		10.7769* (6.2746)							3.3783 (2.3380)
AGDPG			–1.1521*** (0.3969)						–0.7748*** (0.2191)
EXRATE				–0.0000 (0.0000)					–8.49e-12 (2.43e-11)
FTTRADE					0.0004 (0.0034)				0.0044 (0.0030)
HC						0.0062 (0.0042)			0.0053 (0.0050)
INFLA							0.0000 (0.0001)		4.92e-05 (4.92e-05)
									–0.0056 (0.0184)
POPG								0.1739 (0.1859)	–0.9352** (0.3918)
CONSTANT	0.0248 (0.0418)	–0.9496* (0.5194)	0.0638 (0.0471)	0.0246 (0.0414)	0.0017 (0.2254)	–0.4263* (0.2590)	0.0252 (0.0427)	–0.3057 (0.3289)	–8.49e-12 (2.43e-11)
Model diagnostics									
Observations	2,347	2,347	2,347	2,340	2,347	2,239	2,346	2,347	2,235
Countries	114	114	114	114	114	113	114	114	113

1. Values in parenthesis are Windmeijer's (2005) finite-sample correction as the default two-step standard errors are biased in finite samples due to the neglected sampling error in the weighting matrix. 2. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. 3. All models estimated with GMM (xtdpdgmm in Stata) using the collapse option to control for instrument proliferation.

Table 4. Estimations and robustness checks for the effect of foreign direct investment on trade openness.

	(19)	(20)	(21)	(22)	(23)	(24)	(24)	(26)	(27)
VARIABLES	*ATO*	*ATO*	*ATO*	*ATO*	*ATO*	*ATO*	*ATO*	*ATO*	*ATO*
L.ATO	1.0482*** (0.0011)	1.0174*** (0.0188)	1.0480*** (0.0010)	1.0482*** (0.0011)	1.0479*** (0.0019)	1.1107*** (0.0181)	1.0483*** (0.0011)	1.0528*** (0.0033)	1.1116*** (0.0181)
AIFDI	1.5770 (1.0206)	1.3055 (1.0604)	1.4877 (1.0466)	1.5777 (1.0235)	1.5557 (1.0434)	2.5702** (1.0243)	1.5339 (1.0205)	1.4261 (0.9688)	2.0284** (0.9029)
AOFDI	–0.0052 (0.1194)	–0.2510 (0.4114)	–0.0952 (0.1177)	–0.0093 (0.1223)	–0.0237 (0.1323)	–0.1339 (0.1423)	–0.0219 (0.1235)	–0.0905 (0.1701)	–0.0792 (0.1202)
AINV		16.7347* (9.1374)							4.4784 (2.8000)
AGDPG			–1.5769** (0.7245)						–0.9604*** (0.2828)
EXRATE				–0.0000*** (0.0000)					–8.04e-11** (4.00e-11)
FTTRADE					0.0018 (0.0062)				0.0064* (0.0036)
HC						0.0068 (0.0046)			0.0058 (0.0049)
INFLA							0.0000 (0.0000)		3.35e-05 (2.58e-05)
POPG								0.3380 (0.3292)	0.0169 (0.0267)
CONSTANT	–0.0078 (0.0355)	–1.5124* (0.7926)	0.0532 (0.0604)	–0.0067 (0.0361)	–0.1196 (0.3792)	–0.5035* (0.2719)	–0.0079 (0.0350)	–0.6356 (0.6162)	–1.2819*** (0.4048)
Model diagnostics									
Observations	2,347	2,347	2,347	2,340	2,347	2,239	2,346	2,347	2,235
Countries	114	114	114	114	114	113	114	114	113

1. Values in parenthesis are Windmeijer's (2005) finite-sample correction as the default two-step standard errors are biased in finite samples due to the neglected sampling error in the weighting matrix. 2. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. 3. All models estimated with GMM (xtdpdgmm in Stata) using the collapse option to control for instrument proliferation.

Table 5. Complete models for exports, imports, and trade openness.

	(9)	(18)	(27)
VARIABLES	*AEX*	*AIM*	*ATO*
L.AEX	0.3633* (0.1950)		
L.AIM		1.0736*** (0.0094)	
L.ATO			1.1116*** (0.0181)
AIFDI	0.6882** (0.2855)	0.8694* (0.4866)	2.0284** (0.9029)
AOFDI	–0.0047 (0.0372)	–0.0215 (0.0732)	–0.0792 (0.1202)
AINV	0.6663*** (0.2268)	3.3783 (2.3380)	4.4784 (2.8000)
AGDPG	–0.1026*** (0.0348)	–0.7748*** (0.2191)	–0.9604*** (0.2828)
EXRATE	–2.41e-11 (1.65e-11)	–8.49e-12 (2.43e-11)	–8.04e-11** (4.00e-11)
FTTRADE	0.0005 (0.0006)	0.0044 (0.0030)	0.0064* (0.0036)
HC	0.0046*** (0.0017)	0.0053 (0.0050)	0.0058 (0.0049)
INFLA	1.42e-07 (5.59e-06)	4.92e-05 (4.92e-05)	3.35e-05 (2.58e-05)
POPG	0.0009 (0.0075)	–0.0056 (0.0184)	0.0169 (0.0267)
CONSTANT	–0.1823 (0.1237)	–0.9352** (0.3918)	–1.2819*** (0.4048)
Model diagnostics			
Observations	2,235	2,235	2,235
Countries	113	113	113
Probability of 2nd order serials	0.7288	0.4430	0.9352
Probability of the Sargan-Hansen test	0.3024	0.1282	0.1002

1. Values in parenthesis are Windmeijer's (2005) finite-sample correction as the default two-step standard errors are biased in finite samples due to the neglected sampling error in the weighting matrix. 2. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. 3. All models estimated with GMM (xtdpdgmm in Stata) using the collapse option to control for instrument proliferation.

and other resources. The abuse of the system can cause an increase in imports of agricultural resources. Also, the expatriates as well as the growing middle class of developing countries' populations tend to develop a taste for foreign foods. These also contribute to an increase in agricultural exports. Our finding is consistent with the theoretical position of Antras and Caballero [32] of complementarity of trade and capital flows but contrary to those of the Hecksher-Ohlin-Mundell position. Our finding is also inconsistent with the findings of Djokoto [17] and Latif and Younis [18] on the agricultural sector of Ghana, Jordan, Morocco, Egypt, and Thailand, respectively. These reported negative and neutral effects, respectively.

The effect of *AIFDI* on trade openness is also positive. The elastic magnitude of 2.0284 implies that a US$ 1 increase in *AIFDI* would induce a more than US$ 1 increase in trade openness. The estimate turns out to be the highest among the statistically significant estimates. The elasticity can be attributable to the complementarity of *AIFDI* and imports and exports on one hand and the synergistic effect of imports and exports on the other. Theoretically, foreign direct investment and trade are related [29-31]. Whilst Hecksher [29], and Mundell [30,31], posited a substitution effect, Antras and Caballero [32] noted a complementary effect in line with our findings. Our findings are consistent with empirical evidence from developing countries [14,15,19,20]. Whilst Umar et al. [21] found a negative effect for lower-income countries and lower-middle-income countries, a neutral effect was reported for upper-middle-income countries. This result points not only to the presence of capital flows and trade in developing countries but also to a significant trade-enhancing role of *AIFDI* in developing country agriculture. As foreign capital and trade are proxies of globalisation [54-56], these pointers are evidence of the globalisation of agriculture in developing countries.

The coefficients of *AOFDI* on exports, imports and trade openness are negative and statistically insignificant. Recalling that the *AOFDI* was measured as a dummy, the negative sign suggests fewer observations of *AOFDI* than non-observation of *AOFDI.* This is not surprising as developing countries are not generally the source of foreign capital, rather they are recipients [22-27]. Dunning [57] and Dunning and Narula [58] theorised that developing countries are in stages I and II of development in which the inflow of FDI outstrips the outflow of FDI. Although empirical evidence shows some developing countries have moved to stage III [59-64], many developing countries are still far from becoming a net exporter of capital. Our finding is inconsistent with the theory of substitution [29,26,30] and complementarity [32] between capital flows and trade. Our findings also departed from the statistically significant positive effect of OFDI, and trade found by Sun and Zhang [28].

4.4 Discussion of Control Variables

The coefficients of *AINV* are positive but statistically significant for exports. Thus, a US$ 1 increase in *AINV* will induce less than a US$ 1 (66 cents) increase in exports. Exports originate from the supply which also arises from production. *AINV*, therefore, contributes to agricultural exports. This is consistent with the findings of Osei et al. [33] and Tahir et al. [43].

The coefficients of *AGDPG* are negative and statistically significant for exports, imports, and trade openness. It was expected that an increase in output would contribute to the production, supply, and export of commodities, hence a positive effect. However, this did not turn out to be the case. Regarding imports, the negative sign suggests a substitution effect of agricultural growth and imports. An increase in agricultural output would lead to increased provision of agricultural goods that would otherwise have been imported. Whilst this is consistent with Mbogela [34] for African countries and Osei et al. [33] for lower-middle-income countries, others have reported a positive effect [15,19,21,28,43].

The negative coefficient of *EXRATE* suggests increasing currency value per US$ would discourage trade openness. Although increasing *EXRATE* would provide increased local currency sales revenue from exports, the cost of production for export would go up and ultimately discourage exports. For imports, it is a truism that increased *EXRATE* means imports become more expensive, discouraging imports. The combination of these explains the negative relationship between *EXRATE* and *ATO*, albeit a minuscule value. Umar et al. [21] found a positive sign for *EXRATE* for lower-middle-income countries but a neutral effect for lower-middle-income and upper-middle-income countries.

The coefficient for *FTTRADE* is positive for all three models in Table 5 but weakly significant for model 27. Thus, freedom to trade internationally enhances trade openness. This result is expected because the freedom to trade reduces the constraints to trade, thus, encouraging trade. The neutral effect of *FTTRADE* found by Mbogela [34] disagrees with our findings.

The coefficient of *HC* is positive for exports, imports, and trade openness. However, the magnitude is statistically indistinguishable from zero for the export model. *HC* contributes to labour. Recalling that the marginal productivity of labour is positive, HC would enhance production, the source of export supplies. Tahir et al. [43] and Umar et al. [21] also found a human capital-enhancing role in trade, albeit for trade openness. The positive finding of Umar et al. [21] was about upper-middle-income countries. For lower-income countries, however, Umar et al. [21] reported a neutral effect. Aihu and Chedjou [14] reported a neutral effect of *HC* for all the trade measures.

The coefficients of *INFLA* and *POPG* are statistically indistinguishable from zero regarding exports, imports, and trade openness. The results for inflation are contrary to the negative effects reported by Osei et al. [33]. Our results for the population are also consistent with those of Osei et al. [33] for trade openness. Whilst Harding and Javorcik [15] reported a negative effect on exports, Karaca et al. [19], Mbogela [34], and Sun and Zhang [28] found positive effects of population on trade openness. It must be noted that some results are inconsistent with the previous literature, such as the effect of inflation or population. This may be because all countries are considered for the analysis at the same time, and no differentiation is made at all. Consequently, the effect of certain variables on the data in specific types of countries remains obscured.

5. Conclusions and Recommendations

Following gaps in the trade and capital flow literature regarding agriculture, we estimated the effect of FDI on exports and imports and trade openness, using 115 developing countries from 1995 to 2020 taking account of endogeneity in macroeconomic variables. Whilst *AIFDI* has a positive effect on *AEX* and *AIM*, the effect of the latter is higher than that of the former. The larger effect of the latter over the former would impose foreign exchange pressure on developing countries. The estimate of the coefficient of *AIFDI* on trade openness turns out to be the highest among the statistically significant estimates. Freedom to trade internationally enhanced trade openness. Agricultural output growth and exchange rate did not enhance trade, however, measured. Human capital enhanced exports. *AOFDI*, *INFLA* and *POPG* had no effect on trade however measured. To escalate international trade in agricultural products, developing countries must continue to promote *AIFDI*. This requires paying attention to appropriate management of the macro economy; keeping down the inflation rate, optimising the currency exchange rate, and keeping interest rates down to boost investment among others. Whilst these would enhance *AIFDI* that would promote trade, these would directly promote trade. As developing countries have often suffered foreign exchange pressures, they must enhance foreign exchange receipts through increased exports. Increasing human capital can increase exports. This would provide the needed labour for production and increase supplies that lead to increased exports. Developing countries must continue to support measures that promote freedom to trade. As many developing countries have acceded to the World Trade Organisation agreement, it provides a regimen that will compel developing countries to follow policies that make for more free trade among members.

A limitation of this study lies in the absence of partial analysis by country groups, which would have provided a better understanding of the phenomenon under study. This study is also limited to developing countries that are net recipients of AIFDI. Further research can consider developed countries and transition economies.

Author Contributions

Charlotte Badu-Prah: Contributed data and analysis tools; Wrote the paper; Reviewed the paper. Akua A. Afrane-Arthur: Contributed data and analysis tools; Wrote the paper; Reviewed the paper. Ferguson K. Gidiglo: Contributed data and analysis tools; Wrote the paper, Reviewed the paper. Francis Y. Srofenyoh: Contributed data and analysis tools; Wrote the paper, Reviewed the paper. Kofi Aaron A-O. Agyei-Henaku: Contributed materials, and analysis tools; Wrote the paper, Reviewed the paper. Justice G. Djokoto: Conceived and designed the experiments, Analysed and interpreted the data Wrote the paper; Reviewed the paper.

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Data Availability

Data used in the study were extracted from publicly available international sources.

Conflict of Interest

All authors disclosed no conflict of interest.

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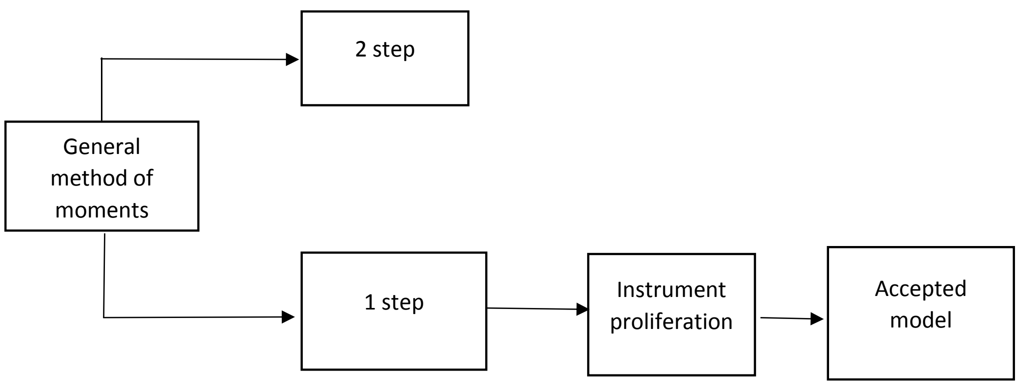
Appendix 1. List of acronyms.

AEX	Agricultura exports
AGDPG	Agricultura GDP growth
AIFDI	Agricultural inward foreign direct investment
AIM	Agricultural imports
AINV	Agricultural investments
ATO	Agricultural trade openness
EXRATE	Exchange rate
FDI	Foreign Direct Investment
FTTRADE	Absence of tariff and non-tariff barriers on trade
GDP	Gross Domestic Product
HC	Human capital
IFDI	Inward foreign direct investment
INFLA	Inflation
LIC	Lower income
LMIC	Lower-middle-income countries
OFDI	Outward foreign direct investment
POPG	Population growth rate
TRADE	Trade
UMIC	Upper-middle-income countries

Appendix 2. List of developing countries in the data.

Afghanistan	**Comoros**	**India**	**Morocco**	**Singapore**
Algeria	Congo	Indonesia	Mozambique	Solomon Islands
Angola	Congo, DR	Iran	Namibia	South Africa
Bahamas	Costa Rica	Iraq	Nepal	Sri Lanka
Bahrain	Côte d'Ivoire	Israel	Nicaragua	Suriname
Bangladesh	Djibouti	Jamaica	Niger	Syria
Barbados	Dominica	Jordan	Nigeria	Tanzania
Belize	Dominican Rep.	Kenya	Oman	Thailand
Benin	Ecuador	Kiribati	Pakistan	Timor-Leste
Bolivia	Egypt	Kuwait	Panama	Togo
Botswana	El Salvador	Laos	Papua New Guinea	Tonga
Brazil	Equatorial Guinea	Lesotho	Paraguay	Trinidad and Tobago
Brunei Darussalam	Eswatini	Liberia	Peru	Tunisia
Burkina Faso	Ethiopia	Libya	Philippines	Türkiye
Burundi	Fiji	Madagascar	Republic of Korea	Uganda
Cabo Verde	Gabon	Malawi	Rwanda	UAE
Cambodia	Gambia	Malaysia	Saint Lucia	Uruguay
Cameroon	Ghana	Maldives	Saint Vincent and the Grenadines	Vanuatu
Central African Republic	Guatemala	Mali	Sao Tome and Principe	Venezuela
Chad	Guinea	Mauritania	Saudi Arabia	Viet Nam
Chile	Guinea-Bissau	Mauritius	Senegal	Yemen
China, mainland	Guyana	Mexico	Seychelles	Zimbabwe
Colombia	Honduras	Mongolia	Sierra Leone	



Appendix 3. Data analyses strategy.

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RESEARCH ARTICLE

Demonstration of Improved Banana (William-1 Variety) Production and Commercialization in Nyanghtom District of South Omo Zone, Southern Ethiopia

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Abstract: A demonstration of improved banana production and commercialization was conducted in the Nyanghtom district of the South Omo Zone to enhance the livelihoods of pastoralists and agro-pastoralists in the area. One improved banana variety (Wiliyams-1) was used for the demonstration and planted on one hectare of land after training was given for purposively selected 25 trial pastoral agro-pastoral research and extension groups and 7 nontrial agro-pastorals from land preparation to harvesting. Relevant data through individual interviews and measurement of agronomic parameters were collected. The collected data were analyzed by descriptive statistics and Likert scale measurement of agro-pastoral preference. Based on the results, the mean banana fruit produced was 28.4 ton ha^{-1} under agro-pastoral management and also agro-pastoral preference indicated that the variety Wiliyam-1 was the first choice of agro pastorals in all parameters except drought resistance. Cost-benefit analysis results indicated that the average net income obtained from banana production was 209,647 Ethiopian Birr ha^{-1}. The cost-benefit ratio of 2.95:1 indicated that the benefit of production was nearly three times higher than the cost of production. However, agro-pastoral raised the frequent breakdown of water pumps, lack of operation and maintenance skills, and the high cost of fuel to operate generators and tractors were major bottlenecks to sustaining production. Therefore, strong efforts of respective stakeholders are needed to resolve irrigation water access problems for sustainable banana production and commercialization to ensure food security and improve the livelihoods of women and agro-pastorals.

Keywords: Banana; Agro-pastoral; Demonstration; Preference; PAPREG

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1. Introduction

The Banana (*Musa paradisiacal var. sapiertum*) is one of the most popular monocotyledon herbaceous fruit plants which are grown throughout tropical humid areas [1]. In 2020, the world production of bananas was 120 Mt from the cultivating land of 5.2 million hectares [2]. It is the fourth-largest global food commodity and is considered to be one of the most important to food security for 400 million people in producing countries [3]. Banana fruits are known for their high nutritional values, sugar and vitamins A, B and C, as well as minerals, particularly potassium, calcium, sodium and magnesium [4].

In Ethiopia, Banana production is concentrated in the southern and southwest regions and the major produce comes from small-scale growers for home consumption and the national market as well as a source of income. Recently, 898,354.81 tone bananas were produced from 95,954.13 hectares of land in Ethiopia and about 118,536.81 tones of banana production are found from 15,358.74 hectares in the Southern Nations Nationalities and Peoples Regional State (SNNPRS) [5]. On the other hand, banana production in the South Omo Zone of SNNR is mainly produced in home gardens and used for home consumption rather not for commercial purposes. However, recently the promotion of different irrigation systems, which is linked with the production of fruits and vegetables all over the country, banana production in the South Omo Zone especially in lowland areas is coming into outlining and a recent year later it is expanded to Dasenech district of South Omo Zone [6]. Because of the high temperature and exclusive access to Omo River banks, it is blessed with favorable soils for the production of fruit crops. However, beyond to use of those resources properly for crop production, residents are suffering for food insecurity [7]. Towards that, Jinka Agricultural Research Center (JARC) has introduced and evaluated banana varieties in the pastoral area of the South Omo Zone to alleviate food insecurity and nutrient deficiency problem.

The report of Jinka Agricultural Research Center's unpublished data indicated that Dwarf Cavendish and William-1 banana varieties were identified as high-yielding and adapted varieties in lowland areas of the South Omo Zone. But those selected improved banana varieties are not well promoted and commercialized all over pastoral areas of the South Omo Zone. Making use of improved technologies, adaptable crops, high-yielding cash crops and linking to market access may help to cope with food insecurity and would enhance the income status of the pastoral and agro-pastoral households in the area. To this end, Jinka Agricultural Research Center in collaboration with different partners is one of the major efforts extended to promote and commercialize improved banana variety in the pastoral and agro-pastoral area of South Omo Zone. Thus, the objective of this study was to demonstrate improve (William-1) banana variety production in the Nyanghtom district of the South Omo Zone and to establish orchards for sucker multiplication.

2. Material and Methods

2.1 The Description of the Study Area

The present study is conducted at Nyanghtom district of the South Omo Zone, SNNPR in the year 2022/2023 cropping season. The district has 20 kebele administration (1 urban and 19 rural) covering 2652 km^2 and located at 4.850-5.670 N and 35.750-36.230 E. The total human population of the districts is 22,562, of which 11,375 are male and 11,187 are female according to population projection by the central statistical agency [5]. The population density is estimated to be 8 persons per km^2. The district is bounded to the north by Bench Maji zone and Salamago district, to the south by Dasenech district, to the east by Hamer district, and to the west by Kenya and South Sudan. The agroecology of the district is lowland, with an altitude that ranges between 300 and 450 m.a.s.l. The mean annual temperature of the district ranges between 33 and 420 °C. The rainfall in the district is erratic and the mean annual rainfall ranges from 350 to 500 mm. Livestock production is the dominant livelihood source whereas beekeeping and fishing are also important income sources in the district. The second most important source of livelihood is opportunistic crop production with an overflow of the Omo River. But recently, sorghum, maize, haricot bean, onion and banana are the major crops produced in the area. More importantly, the district does have huge potential for the production of bananas due to the availability of the Omo River for irrigation.

2.2 Pastoral Agro-Pastoral Research and Extension Group (PAPREG) Member Formation and Identification of Technology Demand

Before the demonstration of this improved banana variety production and commercialization in the study area there was community-level problem analysis with the PAPREGs and non- beneficiary's pastoral and agro-pastoral research group members. In this regard, 25 pastorals were grouped into one PAPREG which was composed of 12 males and 13 females based on interest in the topic, willingness and capability of managing trials and consensus among the members. Group discussion with trial PAPREGs and non-trial agro pastorals was done to analyze the problems in the production and demand of the

PAPREGs for the technology.

2.3 Site Selection

The study site was selected in discussion with district experts of Livestock and Fishery Resources, Agriculture and Natural Resources, Pastoral and Agro-pastoral affair, Lowland Resilient Project and researchers of the Jinka Agricultural Research Center. One kebele was identified namely Narogoy for initial demonstration purposes and used for further teaching and learning of other kebeles which was taken into consideration the possibility of clustering of agro-pastoralist, land and irrigation access.

2.4 Design and Varieties

One selected banana variety (Wiliam-1) was planted with a single large plot that contain 100 * 100 m. The land was divided into 25 equal parts with 12 * 44 m for each PAPREG member. Row planting method was employed and spacing of 3 m * 3 m between inter and intra-spacing. Full recommended management packages for banana production (improved variety, row planting, weed management, irrigation scheduling and, etc.) were conducted.

2.5 Training and Promotion Technique

The training on agronomic practices and irrigation water use was given to selected trial PAPRGs and non-trial agro-pastoralists, development agents and administrators of the kebele to enhance awareness and skills on field management and all other banana agronomic practices and postharvest handling before starting panting. The field visit was conducted just the crop is coming to the maturity stage. Trial PAPREGs members, non-trial agro-pastoralists, experts and other relevant stakeholders were invited to acquire experience and learn about improved banana cultivation.

2.6 Implementation Process, Field Management, and Follow up

First, the selected site was cleaned by human power and prepared for plantation using a tractor. A total of one hectare was ready for 25 PAPREGs, each having a share of 0.04 ha of land to plant. After land preparation was well done, holes of 60 cm in width, depth and length were manually prepared using a spacing of 3 m * 3 m for square planting. Healthy 1111 suckers were planted at the prepared hole. Since the area is arid, irrigation was applied using furrow irrigation. Water was applied at 3-day intervals at the initial stage and once within a week after the canopy was covered uniformly. Re-shaping of holes and earthling up around the crop was done to prevent the outbreaking of irrigated water and conserve water near the plant. Weeding was performed when weeds occurred. After planting the sucker, researchers from Jinka Researcher Center, and experts from the zone and district of Low Land Resilient project office conducted frequent follow-ups and evaluated the progress. Feedback regarding the weakness and strengths of each PAPREG were given to further improve the management and irrigation water access. This feedback gave the lesson to strengthen those with weak management of their plot and share good experiences with those with good management of their plot. Moreover, at different stages of production, regional coordinators of the Low Land Resilient Project and Southern Agricultural Research Institute conducted follow-up, and evaluation and gave feedback. All these coordinated efforts resulted in the successful demonstration and production of improved banana variety production in the study area.

2.7 Data Datasets and Recording

Important data sets collected include PAPREGs variety preference of improved banana, frequency of harvest, number of bunches per harvest, the total number of bunches per hectare, the weight of bunch per kilogram and the selling price of a one-kilogram banana. Data was collected by measuring each parameter with a data collection sheet and face-to-face interviews with PAPREGs using structured questionnaires. Moreover, lessons learned and feedback on important attributes of improved banana production technology were collected through group discussions with PAPREGs. The organization of groups was based on the interest of PAPREGs to participate in the discussion regarding improved banana production technology and the group constituted ten different social members such as elders, women and youth pastorals.

2.8 Data Reporting System

This study used both quantitative and qualitative data sets. Quantitative data includes frequency of harvest, number of bunches per harvest, the total number of bunches per hectare, the weight of bunch per kilogram and the selling price of a one-kilogram banana, and analyzed using simple descriptive statistics (percentage, mean and maximum and minimum). Qualitative data sets include PAPREGs' variety preference of improved bananas and constraints of banana production were analyzed using the Likert scale and ranking. The benefit-cost ratio was used to analyze the profit from the production of bananas in the study area.

3. Results and Discussion

3.1 Household Characteristics of PAPREGs

An effort was made to assess the household characteristics of the sample respondents as shown in Table 1. Consequently, about 46.9% and 53.1% of the PAPREGs of banana production technology were males and females respectively. This indicates that women were more participated than men in pastoral and agro-pastoral research and extension groups. Furthermore, the Low Land Resilient Project encourages women's participation in every activity they implement to improve their income-earning capacities. Different studies reported that women participate more than men in horticultural crop cultivation [8-10]. Moreover, the study by Hidosa et al. [11] reported that agro-pastoral women participate in panicum grass production more than men as they are nearer to providing livestock feed. The mean age of the respondent was 36 years indicated the PAPREGs involved in banana production technology are productive. Regarding the education level of the PAPREGs, the mean grade achieved was grade one. This implies that the beneficiary's education achievement is very low and there is a dominance of illiteracy in the area as the study area is pastoral and agro-pastoral area. The minimum and maximum family size of PAPREGs was two and nine. The mean family size of the respondent was 6. This implies that family size in the household has some role in the labor force to engage in different income-generating activities like banana production in addition to livestock production activities. A similar finding was reported by Tadesse et al. [12] that the average family size of the households is 6 persons in the Nyanghtom district.

It is clear that the district has huge potential for water and land resources for banana production using the Omo River, but yet they have not been involved in improved banana production. Recently Jinka agriculture research center in collaboration with Low Land Resilient Project introduced improved bananas and demonstrated them to the agro-pastoral. Thus, the PAPREGs have one-to-two-year experiences in improved banana production. This implies that they are new to the improved banana production technology and enough training and strong support was provided to them to successfully produce and get benefits. The minimum, maximum and mean numbers of family members who engaged in banana production technology were 1, 7 and 3 persons. This implies that the banana production technology in the study area created more jobs for household members. Thus, household members who engaged in banana production technology generate income and reduce the number of family members who have no job thereby improving their livelihood.

3.2 Banana Production Status and Its Importance on Livelihood Improvement

The production status of improved bananas is juvenile that previously they do not have a practice of improved banana production technology. However, they do have a small practice of local banana production using the Omo River for irrigation. As to key informant discussion with district experts planted bananas had also spread in the area and were incorporated into development plans by Pastoral and Agro-pastoral Affairs, agricultural office, Jinka Agricultural Research Center, Lowland Livelihood Resilient Project and other development projects. More importantly, the production area that banana early planted area was increased from one to three hectares. This implies that the demand for improved banana production technology is increasing and has some contribution to livelihood improvement for pastoral and agro-pastoral households. The PAPREGs who are expanding their land indicated that they are solving the sucker shortage problem in their area and selling and sharing the sucker with other neighboring agro-pastoral. As indicated in Table 2, all PAPREGs (100%) agreed that they don't have banana sucker access

Table 1. Household characteristics of sample respondents.

Attributes of respondents		Frequency	Percent	
Sex of household	Male	15	46.9	
	Female	17	53.1	
	Min	Max	Mean	Std. Dev.
Age of respondent (Year)	25	55	36	8.53
Family size (Number)	2	9	6.4	2.19
Education status (Grade)	0	11	1.27	2.98
Banana production experience (Year)	1	2	1.21	2.84
Household member engaged in banana production (Number)	1	7	2.53	1.43

Source: Own survey, 2023.

previously but now there is no sucker access problem in their area to produce and distribute. Inclusively, this indicates banana sucker shortage problem is not a problem now for both the PAPREGs and non-PAPREGs in the area. The reason for not cultivating previously was a lack of knowledge regarding improved banana production technology. As reported by PAPREGs, about 78.1, 15.6 and 6.3% were due to lack of sucker, awareness and support from different stakeholders respectively. Moreover, they indicated there are different benefits of cultivating improved bananas such as household income source, food and livestock feed. About 84.4 percent of PAPREGs reported that the importance of cultivating improved bananas was highly improving whereas 15.6 percent reported slowly improving. This implies that the majority of PAPREGs realized the importance of cultivating improved bananas as their livelihood improvement activity. This finding is identical to the findings of Adhikari et al. [13] who reported cultivation of bananas enhanced household income and improved the livelihoods of producers.

3.3 Household Income Analysis of Banana Production

As far as access to irrigation water is not a problem for agro-pastoral, it is easy to cultivate bananas using irrigation. Once they planted the banana sucker, they frequently water as per plant water requirement and effectively manage weeds, then they do have a continuous harvest of the fruit or duplicate the banana sucker to the surrounding. Once banana planting was established in the area, it has taken 9 months to cut the first banana fruit and later the average harvesting frequency was nearly 1.8 times in a year in the area if properly managed and access irrigation water. However, after first harvesting, later harvesting frequency depends on irrigation water access and weed management, and the minimum, maximum, and average harvesting frequency of improved banana per year in the study area is 1, 2 and 1.8 times respectively. The mean bunch produced per ha/year was 710 bananas bunch and on average each weighs 22.2 kg. This means that the mean amount of bananas produced was 28,371.6 kg per hectare in the area under agro-pastoral management (Table 3). This indicates that the mean yield of bananas was 284 quintals or 28.4 tons per hectare which is a far better yield than in the study by Dawit and Asmare [14] who reported the mean productivity of bananas is in the range of 10 to 20 tons per hectare under farmer management. This might be due to the virgin land which is not previously cultivated, the favorable environment, improved variety, and irrigation water access.

The minimum and maximum price of bananas was 8 and 10 Ethiopian Birr (ETB) per kilogram respectively with a mean price of 9.73 ETB per kilogram. The mean sucker sold by an individual household in a year was 307 and the minimum and the maximum sucker were 125 and 550 respectively. Each sucker cost the mean of 14.5 ETB and the minimum and the maximum price per sucker were 10 and 20 ETB respectively in the production season 2022. The mean income from the sale of the banana fruit per hectare and the sucker was 276,055.7 and 4,551 ETB respectively in the production season 2022. The mean total income from the sale of the banana fruit per hectare and the sucker was 280,606.7 ETB in the production season of 2022. The minimum and maximum total income per individual household generated from the sale of the banana fruit per hectare and sucker were 61,250 and 571,000 ETB (Table 4). This implies that agro-pastoralists who were able to manage improved banana production effectively may generate a maximum income of more than half a million in a single production year per hectare and could harvest continuously as banana is a perennial fruit crop.

3.4 Cost of Improved Banana Cultivation

All costs of improved banana cultivation were recorded by researchers and experts at the implementation site. The main cost items recorded were planting material (sucker), site cleaning and land preparation, planting sucker, ir-

Table 2. Status of banana production in the area.

Attributes		Freq	Percent
Access to improved banana sucker	Yes, now	32	100
	No, so far	32	100
Reason for not cultivating banana	Lack of sucker	25	78.1
	Lack of awareness	5	15.6
	Lack of support	2	6.3
Importance of cultivating improved banana	Highly improving	27	84.4
	Slowly improving	5	15.6

Source: Own survey, 2023.

Table 3. Mean fruit yield and yield-related parameters of the improved banana variety.

Parameters	Min	Max	Mean
Day to 50 % of 1st cycle harvesting	268	290	279
Harvesting frequency per year	1	2	1.8
Bunch produced/ha/year (number)	500	875	710
Weight of bunch (kg)	15	32	22.2
Fruit yield per hectare (tone)	7.5	56	28.4

Source: Own survey, 2023.

Table 4. Income from improved banana cultivation/yield/ha/year.

Attributes	Min	Max	Mean
Total fruit yield/ha/ year (tone)	7.5	56	28.4
Price of banana per kg (ETB)	8	10	9.73
Sucker sold per household/ha/year (number)	125	550	307.5
Price per sucker (ETB)	10	20	14.8
Income from the sale of a fruit per hectare (ETB)	60,000	560,000	276,055.7
Income from the sale of sucker per hectare (ETB)	1,250	11,000	4,551
Total income (ETB)	61,250	571,000	280,606.7

Source: Own survey, 2023.

rigation, weeding management and harvesting. Thus, the average cost of improved banana production per hectare was 70,959 ETB. All the cost items purchased and labor per day prevailed by the current market price at the time of production season. The cost of the sucker was 16,665 ETB per hectare and also others all well described in Table 5.

3.5 Net Income from Improved Banana Cultivation

Table 6 describes the net income of banana cultivation in the study area. The average net income obtained from banana production in one production season was 209,647 ETB per hectare in the study area. This income is the income obtained after the first harvest that has taken nine months after planting and later continuous harvest. This indicates that any agro-pastoral who participated in improved banana production would have a mean net income of 209,647 ETB per hectare. Besides, the ratio of benefit to cost (2.95:1) indicated that agro-pastoral households may get benefit from improved banana production nearly three times higher than the cost of production. This finding suggests that agro-pastoral households who invest in improved banana production would get better income in a single production season and further expand the production of bananas using suckers around the mother plant. And also, this is the most profitable business in the area that would encourage new agro-pastoralists to start with improved banana production to absorb the benefits of this profitable initiative. This finding is in line with others that banana cultivation is an economically profitable investment because of the higher positive returns earned [15-17].

Table 5. Cost of improved banana production per ha.

Expense items	Measurement	Quantity	Unit cost (ETB)	Total cost (ETB)
Sucker	Number	1111	15	1111*15 = 16,665
Land preparation	Fuel by liter	150	69.36	150*69.36 = 10,404
Planting	Person per day	25	100	25*100 = 2,500
Irrigation	Round	50*4	100	50*4*100 = 20,000
Weeding management	Round	10*15	100	10*15*100 = 15,000
Harvesting	Frequency	1.8*710*5	100	1.8*710*5 = 6,390
Total cost				70,959

Source: Own survey, 2023.

Table 6. Net income from banana production.

Income and cost of production	Mean (ETB)
Gross income	280,606.7
Cost of production	70,959
Net income	209,647.70
Benefit: cost ratio	2.95:1

Source: Own survey, 2023.

3.6 Extension Services and Training on Improved Banana Production Technology

Access to extension services has been improved over time due to a result-oriented extension approach in which agro-pastoral could see the yield difference of introduced banana production technology compared to the local one. Implementation of any new agricultural technology needs an effective approach and PAPREGs need to be conscious and responsive to effectively use the given technology and also has got information through extension agents [18]. Information sources about improved agricultural technologies are development agents, agro-pastoral-to-agro-pastoral and experience sharing in the district. As shown in Figure 1, they indicated that the training and extension service on improved banana production technology by the Jinka Agricultural Research Center, lowland Livelihood Resilient Project and District Office of Agriculture was very important. Thus, the training helped them to cultivate improved banana and realized benefit through income generation and household food sufficiency. In addition, about 90% of the PAPREGs reported they are satisfied with the training and extension services provided by different stakeholders whereas 10% did not satisfied. As presented in Figure 2, all PAPREGs (100%) participated in the banana demonstration trail by Jinka Agricultural Research Center whereas about 30% of the respondents get extension services from development agents. This indicated that the extension provision regarding banana production by the development agent is weak. Moreover, about 70% of both trial PAPREG and non-trial agro-pastoral were involved in the collaborative training by the Jinka Agricultural Research Center and Lowland Resilient Project whereas 86% of the respondents participated in final pastoral and agro-pastoral field days. This shows that pastorals and agro-pastoral in the area are participating in different pieces of training from different stakeholders.

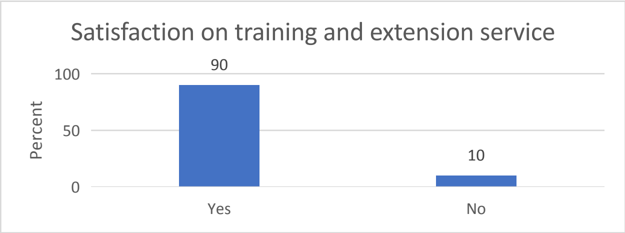

Figure 1. Satisfaction with training and extension services.

3.7 Agro Pastoralists' Trait Preference for Improved Banana Production

The objective of the demonstration is not only to maximize yield but to improve PAPREGs' involvement in selecting technologies that fulfill their preference for sustainable technology diffusion [19]. Thus, agro-pastorals identified six common preference parameters to compare improved bananas (William-1 variety) with local variety. The parameters were weighted according to their impor-

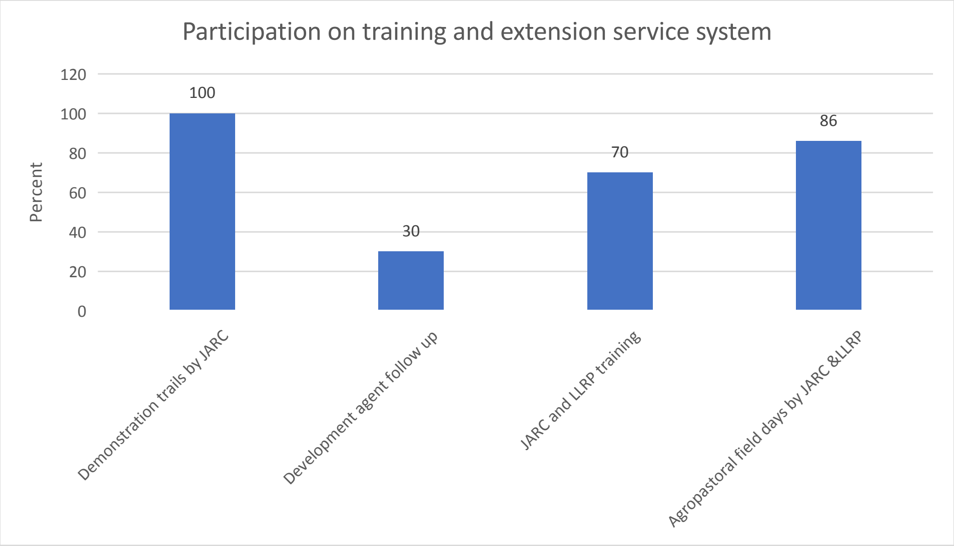

Figure 2. Method of training & extension delivery system.

tance to be used as a comparison, then technology with a greater percentage of the total was selected as the primary choice. The overall weighted ranking matrix result shows that improved banana (William-1) was the first choice of agro pastorals in all parameters except drought resistance whereas their local variety is the first choice only in drought resistance (Table 7). This implies that their local variety is not productive as the improved one but they still appreciate the local variety in drought resistance as compared to the improved variety. However, as the study area is agro-ecologically classified as dry land and described by recurrent rainfall shortage and their production practice of banana is with irrigation from Omo river by motor pump. Agro-pastoral given high score for early maturation, disease resistance and marketability of improved banana as compared to the locally available banana variety.

3.8 Constraints of Banana Production

The frequent breakdown of water pumps is the main constraint that hinders the production of bananas in the area. As the production is based on irrigation water access and lack of water due to pump breakdown order the plant to dry. Thus, the pump and generator breakdown are ranked as the first serious problem and operation and maintenance skills in irrigation systems are a basic necessity for sustainable use of the water lifting device and accessing water for production. The high cost of fuel to operate generators and tractors is another constraint that hinders the production of bananas and is ranked as the second most serious problem. As they are agro-pastoral, they are not capable enough to purchase fuel and the supporting organization in the district are getting on a budget shortage as the recent price of fuel is so high. The study by Asmera et al. [18] and Hidosa et al. [11] reported that the high cost of fuel is the changing factor of panicum production in the Dasenech district. On the other hand, the lack of skills in the maintenance of generators and water pumps is the third important constraint that hinders banana production in the area. Thus, a lack of operation and maintenance skills in irrigation systems for water lifting devices may cause the failures of sustainable production using irrigation and may be associated with food insecurity problems in irrigation-based production-dependent areas. Extensive drought is the key factor that causes the banana to dry and hinders sustainable production. The PAPREGs reported that the recurrent drought is the fourth serious problem that hinders banana production and lets them to food insecurity. Market linkage is another important constraint of banana production as output markets are the main driving force for the products to be sold [20-22] and ensure the economic feasibility of irrigation projects and ensure sustainable production and economic returns. Failure of the market for irrigation-based agricultural products like bananas may cause the failures of irrigation projects and challenges the sustainable use of irrigation. Lastly, they reported that the lack of enough training and support on the production and irrigation of water by districts and stakeholders hinders banana production in the study area (Table 8).

Important lesson

Promotion of new technology to pastoral and agro astral through the PAPREG approach was very important for easiness of communication and contact with any number of PAPREGs at once to demonstrate improved technology. Moreover, it was effective for common problem identification, practical and participatory way of working on the ground, creating awareness and ownership of that technology, sustainable use of demonstrated technology and strengthening the team spirit between PAPREG, extension workers and researchers for the common objective.

Table 7. Preference of agro-pastoral on improved banana (William-1) and local variety.

	Improved (William-1)			**Local**		
Parameters	score	weight	score*weight	score	weight	score*weight
Early maturity	3	1	3	1	1	1
Disease/pest/resistance	3	2	6	1	2	2
Taste	3	3	9	2	3	6
Fruit size	3	5	15	1	5	5
Drought resistance	2	6	12	3	6	18
Marketability	3	4	12	2	4	8
Sum of Score*weight			57			40
Rank			1			2

Score = (1 = Fair, 2 = Good, 3 = V. Good) & Weight = (1 = Early maturity, 2 = Disease resistance, 3 = Taste, 4 = Marketability, 5 = Fruit size, 6 = Drought resistant.

Table 8. Constraints of banana production in the area.

Constraints of banana production	The level of constraints					
	Very serious	Medium	Serious	Score	Index	Rank
The generator and water pump break down	22	8	0	87	0.196	1
High cost of fuel to operator generator and tractor	16	14	0	81	0.182	2
Market linkage problem	6	20	4	67	0.151	5
Lack of skills in maintenance of generator & pump	12	18	0	77	0.173	3
Lack of training and support	12	6	12	65	0.146	6
Extensive drought	7	19	4	68	0.153	4

Note: The value is given for the level of constraints: Very serious = 3, Medium = 2, Serious = 1.

4. Conclusions and Recommendation

The finding of this study indicated that the demonstration of improved banana production and commercialization in the areas has improved the economic status of the PAPREG and non-trial agro-pastoral and contributed to reduce the food security issues through the sale of banana fruit, sucker and feed biomass of bananas after harvesting. Moreover, the PAPREG approach to the demonstration was effective as it is an easy way of identifying practical problems on the ground, creating awareness, ownership of that technology, sustainable use of demonstrated technology and strengthening the team spirit among PAPREG members. The mean banana fruit produced was 28.4 tons per hectare in the area under agro-pastoral management. The average net income obtained from banana production in one production season was 209647 ETB per hectare in the study area. Besides, the ratio of benefit to cost (2.95:1) indicated that agro-pastoral households would get benefit from improved banana production nearly three times higher than the cost of production. Moreover, the agro-pastoral preferred improved banana (William-1) over the local in all parameters except drought resistance whereas their local variety is the first choice only in drought resistance. However, agro-pastoral raised the frequent breakdown of water pumps, lack of operation and maintenance skills, and the high cost of fuel to operate generators and tractors are major problems to sustain production. Therefore, strong efforts of respective stakeholders are needed to resolve irrigation system problems mainly the supply of easy water lifting devices for sustainable banana production and commercialization to ensure food security and improve the livelihoods of women and poor agro-pastoral in the area. Additionally, it could be concluded that PAPREGs should be involved in further expansion and linked with different market outlets like ETFRUIT and other national or regional markets to enhance their income.

Author Contributions

Mr. Atlaw Eshbel developed a proposal and defended, secured the budget, conducted the field experiment, trained beneficiaries and arranged field days, collected all field data, analyzed, and interpreted the result, and wrote the manuscript. Mr. Asmera Adicha prepared data collection sheets, collected data, analyzed, and interpreted the result, and wrote the manuscript. Mr. Anteneh Tadesse secured land, conducted the field demonstration, and arranged the field day and field data collection budgets Mr. Awoke Tadesse was involved in planting, monitoring and evaluation, arranged field day and collected all field data Yibrah Geberemeskel was involved in monitoring and evaluation, field day events and arranged field data collection budgets.

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Data Availability

Data used for this study are available in the text and can be accessed from the corresponding author upon request.

Conflict of Interest

There is no conflict of interest among authors.

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RESEARCH ARTICLE

Investigating the Role of the Cultivated Banana Value Chain as a Potential Source of Sustainable Income for Local Communities in Lao PDR

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Abstract: Cultivated bananas have gained attention due to the environmental and social impacts of Cavendish bananas in the northern part of Laos. This study investigated the value chain of cultivated bananas and its implications for sustainable income generation. Basic statistical analysis was used to assess the value added by cultivated bananas, while stakeholder analysis and value chain mapping were used to identify key actors and relationships. The determinant of commercialization is observed through the regression model and the impact of commercialization is investigated through the second stage regression. The study found that the banana value chain in Laos is driven by the export market. Farmers generate the highest profit, but they receive the lowest distribution of value-added. Banana commercialization can significantly increase the income of farmers, but the impact is not equal for all farmers. Bananas are a sustainable income source for households in Laos, and they have the potential to be promoted in high-value markets if the farmers create new products and improve skills of management, marketing, and finance with the support from government policies.

Keywords: Cultivated banana; Value chain; Commercialization

1. Introduction

In the Lao PDR, which is primarily an agrarian society, agriculture, and forestry contribute to 30% of the country's GDP and employ over 75% of the workforce. The Agriculture Development Strategy 2025 has identified bananas as a prioritized crop for agricultural exports. In 2020, bananas hold significant importance as one of the key crops, with an estimated production of 385,000 tons. The development of commercial banana production, largely driven by Chinese investments, brings economic benefits and employment opportunities, particularly in the northern region of Lao PDR. Approximately 88% of the exported bananas were shipped to China, while the re-

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maining 12% were sent to Thailand.

In recent years, the demand for bananas in neighboring countries has increased, leading to a rapid expansion of banana production and area in Lao PDR. One of the banana types that is being heavily invested in Lao PDR is Cavendish, which is a high-yielding variety that requires extensive use of chemical fertilizers, pesticides, and herbicides. The use of these chemicals has had significant negative impacts on both the environment and the well-being of workers and consumers.

The use of chemicals in banana production can have several negative impacts on the environment, workers, and consumers. Environmental impacts include water pollution, soil contamination, and ecosystem damage. Worker health impacts include respiratory problems, skin problems, and cancer. Consumer health impacts are less well-understood, but there is some evidence that exposure to chemicals in bananas can cause health problems. Workers on banana plantations are often from impoverished communities and may have a limited understanding of safe chemical handling practices. This puts them at even greater risk of exposure to harmful chemicals. The costs of healthcare and environmental rehabilitation may outweigh the benefits of income generation and job opportunities from banana production [1].

Due to concerns over the spread of Fusarium wilt in Cavendish banana plantations in Northern Laos, cultivated banana varieties known locally as "Kuay Nam" have gained increased attention [1]. Cultivated bananas play a crucial role in the agricultural sector of Lao PDR, providing food security and income generation opportunities for local communities. Traditionally, banana plants grew naturally in backyards or small farms for household consumption and animal husbandry. However, in recent years, there has been a growing interest in commercializing Kuay Nam bananas due to their high yields and resistance to pests and diseases.

There has been limited research on the potential of the cultivated banana value chain to provide sustainable income for local communities. To address this gap, this study focuses on investigating the role of the cultivated banana value chain in supporting sustainable income for communities in the provinces of Houaphan, Vientiane, Savannakhet, and Salavan.

Several studies have been conducted to analyze value chains in the Lao PDR. For instance, Wongpit and Sisaphanthong [2] examined the value chain of organic vegetables in Vientiane Capital and found limited value addition and processing due to small market size, lack of knowledge, and low consumer awareness. In another study, Small-scale Agro-Enterprise Development in the upland [3] analyzed the cultivated banana value chain in the Poukoud district, Xieng Khuang Province, identifying challenges such as insufficient inputs and equipment for farmers. However, with access to funding, farmers were able to increase production and sales, highlighting the significance of middlemen in connecting farmers to the market.

The commercialization of agricultural products is a priority policy of the Lao government. Farmers are being encouraged to change from traditional production methods to more commercial practices, such as expanding production and processing their products. The government is providing support to farmers in this transition, such as providing access to credit and training on commercial production techniques. The commercialization of agriculture is expected to benefit both farmers and the economy. Farmers will be able to increase their incomes, and the economy will benefit from increased exports.

The impact of agricultural commercialization on livelihoods and food access in the Lao PDR has been analyzed by Wright [4]. The study highlights policy-driven shifts from traditional to intensive agriculture and increased demand for agricultural products from neighboring countries. These developments have expanded markets and facilitated smallholder access to markets through improved road infrastructure. Goletti [5], Bouahom et al. [6] and Setboonsarng et al. [7] have discussed commercial crop production, there has been a lack of comprehensive examination and quantification of the determinants and implications of agricultural commercialization in the Lao PDR, particularly for crops like cultivated bananas.

This paper aims to describe and analyze the value chain of cultivated bananas in domestic and foreign markets, filling the gap in existing research. To analyze the effects of commercialization on local incomes, this study focuses on the cultivated banana value chains, examining their organization, key actors involved, value added throughout the process, and potential opportunities.

2. Material and Methods

The methodology employed in this study involved the use of value-chain analysis to examine the cultivated banana industry in four provinces. The value chain analysis includes stakeholder analysis, value chain mapping, and value-added. The objective of value chain analysis is to break down the chain into its individual components to gain a better understanding of its structure and functioning [8]. A preliminary value-chain framework was developed based on existing studies, reports, and consultations with researchers. Stakeholders were then invited to participate in a focused group discussion where the draft value chain was presented and explained. Valuable input and suggestions from the participants were incorporated, leading to the revision of the value chain and the identification of key bottlenecks.

The determinants of commercialization were analyzed through a regression model. There are many discussions about what agriculture commercialization is and how to measure commercialization. Govereh et al. [9] suggest that agriculture commercialization is the proportion of sold products to total production and commercialization can be measured along a continuum from zero (total subsistence-oriented production) to unity (100% production is sold). The measurement of the commercialization of agricultural pre is expressed as the equation below:

$$Commercialization = \frac{Sale\ value}{Production\ value} \tag{1}$$

The agricultural product in this paper refers to cultivated bananas. The sale value is the value of cultivated bananas that farmers sell to middlemen or exporting companies. Production value is the value of cultivated banana production by farmers. The equation model to identify the determinants of banana commercialization is as follows:

$$C_i = \alpha_0 + \alpha_1 Age_i + \alpha_2 Edu_i + \alpha_3 Exp + \alpha_4 Mem + \alpha_5 Dm + \alpha_6 Df + \varepsilon_i \tag{2}$$

Household income, I_i, is a function of instrumented agricultural commercialization ($\widehat{c_i}$), labor, capital, and land; a vector of household characteristics (H_i); and a government policy variable, P_i.

$$lnI_i = \beta_1 + \beta_1 \widehat{C}_i + \beta_2 lnK_i + \beta_3 lnL_i + \beta_4 lnS_i + \beta_5 P + \beta_6 D_2 + \beta_7 D_3 + \beta_8 D_4 + \varepsilon_j \tag{3}$$

The definition and measurement of variables in Equations (2) and (3) are explained in Table 1.

Data for the study were collected through a household survey conducted in four provinces: Houaphan, Vientiane, Savannakhet, and Salavan. Banana production has increased significantly in recent years, particularly in Vientiane Province, Salavan Province, and Savannakhet Province. In Xanakham district, Vientiane Province, which is located in the central part of Laos, most of the bananas are sold to Vientiane Capital or exported to Thailand. Some of the bananas are also processed into banana crisps and solar-dried bananas. Salavan Province is in the southern part of Lao PDR where most of the bananas are exported to Thailand. Some bananas are also used to produce whiskey or processed into banana fiber for handicrafts. However, the demand for these products is low. In Houaphan Province, which is in the northern part of Laos and shares a border with Vietnam, the commercialization of cultivated bananas is at an early stage. The main obstacles to the expansion of banana production are the lack of a market, the high costs of materials and transportation, and the limited availability of land. In Savannakhet Province, bananas

Table 1. Definition and measurement of the variables.

Variable	Definition	Measurement
C	Commercialization ratio	The ratio of the value of the banana sale to the total production value where rank from 0 to 100
Gen	Gender	Gender of the head of the household where 1 is male and 2 is female
Age	Age	Age of head of household
Edu	Education	Year of education of the head of household
Exp	Experience	Year of experience in the banana plantation
Mem	Member of household	Number of members in the household
Dm	Distance to market	Distance from farm to market in Kilometers
Df	Distance to farm	Distance from home to farm in Kilometers
lnI	Natural logarithm of to income of the household	Total income of a household in million Lao Kip (LAK) per year
$\widehat{C}$	Predicted commercial ratio	Predicted commercial index derived from Equation (2)
lnL	Natural logarithm of labor	Number of workers used to cultivate bananas
lnK	Natural logarithm of capital	Value of capital use in the banana farm in million LAK per year
lnS	Natural logarithm of land	Land area of the banana farm measuring in hectares
P	Policy	Dummy variable for policy support where 1 if received support and 0 otherwise
D1	Dummy variable for Houaphan	1 is Houaphan and 0 otherwise
D2	Dummy variable for Vientiane	1 is Vientiane and 0 otherwise
D3	Dummy variable for Savannakhet	1 is Savannakhet and 0 otherwise
D4	Dummy variable for Salavan	1 is Salavan and 0 otherwise
ε_i	Error term	

are mainly planted in the Xepon district, near the border with Vietnam. Most of the bananas are exported to China through Vietnam.

The selection of districts within each province was based on recommendations from provincial authorities actively promoting agriculture commercialization. Random sampling methods were used to select households, middlemen, and banana processors for interviews. The survey questionnaires covered various topics such as respondent information, revenue, production costs, market accessibility, and financial access. The interviews aimed to gather the necessary information. Table 2 shows the sample size which consists of 474 households involved in banana cultivation, along with 8 middlemen and 9 banana processors.

Table 2. Sample size across the different categories.

Provinces	Farmers	Middlemen	Processors
Houaphan	111	2	2
Vientiane	251	3	3
Savannakhet	73	2	3
Salavan	36	1	1
Total	474	8	9

Source: Authors' survey in 2017.

3. Results

3.1 Value Chain of Cultivated Bananas

Value Chain of Cultivated Banana in Huaphan

In the banana value chains in Houaphan Province, four main stakeholders can be identified: farmers, processors, middlemen, and importers. Farmers are responsible for cultivating and collecting bananas from their farms and selling them to middlemen and customers at the market in Xam Nuea district. On average, farming households have a farm area of 1.3 hectares, with 0.6 hectares dedicated to banana farming. The total cost of banana production for farmers, including fixed and variable costs, amounts to approximately 2.02 million LAK per household per year. In contrast, the total income from bananas reaches around 3.06 million LAK per household, resulting in a profit of approximately 1.04 million LAK.

Processors in Houaphan purchase bananas from farmers and use them to produce ripe banana crisps. It takes about four hours to produce ripe banana crisps from 20 bunches of bananas. Processors sell these banana crisps directly to customers at the market in Houaphan Province. The main costs incurred by processors include fixed costs for equipment and variable costs such as labor, purchasing bananas, cooking oil, and packaging materials. On average, processors earn an income of 1.5 million LAK per month, while their total costs amount to 0.9 million LAK, resulting in a profit of 0.6 million LAK per month.

Middlemen play a role in buying bananas from farmers and selling them to customers in the market in Xam Nuea district. Their fixed costs primarily include trucks, while their variable costs consist of expenses for gasoline, rental fees at the market, maintenance, and labor. The average total cost for middlemen is 13 million LAK per month, and their income amounts to 4 million LAK per month. Consequently, the average profit for middlemen is 9 million LAK per month.

Figure 1 depicts the value chain map of cultivated bananas in Houaphan Province. The percentages displayed above the arrows represent the market share of each stakeholder. Farmers utilize three distribution channels, selling 20% to middlemen, 10% to processors, and 70% directly to customers at the market in Xam Nuea district. Middlemen acquire Kuay Nam bananas from farmers, distributing 75% to consumers at the market, 20% to processors, and exporting 5% to Vietnam. The quantity of processed bananas is relatively low, with processors producing banana chips or grilled bananas for sale in the local market.

The distribution of value-added among the stakeholders in each channel. Farmers achieve an average profit of approximately 753 LAK/kg, corresponding to a profit margin of 193%. Middlemen obtain profits of 1,316 LAK per bunch, representing a profit margin of 78%. Their sale price amounts to 20,000 LAK/kg or 28 packs, resulting in a profit of 3,098 LAK/kg or an 18% profit margin.

Value Chain of Cultivated Banana in Vientiane Province

In the value chain of bananas in Vientiane Province, there are four main stakeholders: farmers, processors, middlemen, and distributors. Farmers collect bananas from their farms and sell them, with an average farm area of 3.7 hectares per household and 2 hectares dedicated to banana farming. The average total cost of banana production is 3 million LAK per household per year, while the total income from bananas amounts to 13.7 million LAK per household, resulting in a profit of approximately 10.7 million LAK per household.

Processors in Vientiane produce various banana products, with the knowledge and techniques transferred from JICA. The production process for banana crisp takes 8 hours with 3 workers, using around 400 bunches of bananas to produce 220 kg of banana crisp. Solar-dried banana production requires 4 man-days and 300 bunches of

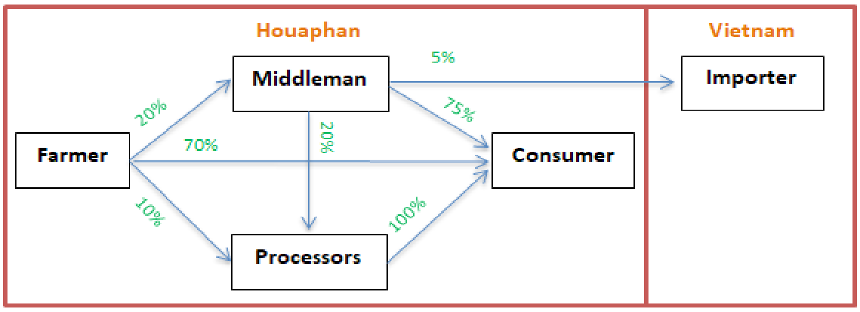

Figure 1. Mapping of value-chain of cultivated banana in Houaphan Province.

bananas to produce 125 kg. Processors sell their products to retailers in Vientiane Capital and occasionally export to retailers in Thailand, generating an average monthly revenue of 8 million LAK and a profit of approximately 2.5 million LAK.

Middlemen purchase bananas from farmers and sell them to customers at the market in Vientiane Capital. Their main fixed costs include trucks, and variable costs consist of gasoline, rental fees, maintenance, and labor costs. The average monthly income and cost for middlemen are 27 million LAK and 20 million LAK, respectively, resulting in an average profit of 7 million LAK per month.

Distributors, a Lao-China joint company, are responsible for collecting, packing, and exporting bananas to distribution centers in China. The bananas are then distributed to markets, retail shops, or department stores in China. Occasionally, Thai importers buy bananas directly from the farm when there is a supply shortage in Thailand. The demand for processed bananas from retail shops and markets in Thailand is irregular.

Figure 2 shows that approximately 50% of bananas are sold in the domestic market, primarily at the market in Vientiane Capital. Processors purchase 10% of bananas from farmers for their production. For export, around 15% of bananas are sold to the distributor and exported to China, while 5% are exported to Thailand. Processors sell 80% of their total product to retailers, 15% to domestic customers, and 5% to Thai importers. Middlemen sell 90% of the bananas to retailers at the market and 10% to customers in Vientiane Capital.

The average profit for farmers selling bananas in Lao PDR is approximately 153 LAK/kg, resulting in a profit margin of around 16%. Middlemen, who act as intermediaries, make an average profit of 3,000 LAK/kg, equating to a profit margin of approximately 23%. Processors in the industry produce four flavors of banana crisps and solar-dried bananas, with an average profit margin of around 77%. Retailers purchase processed bananas from processors, pack them into small packages, and sell them in retail shops, achieving a profit margin of approximately 50%. Additionally, retailers also sell unprocessed bananas, gaining an approximate profit margin of 67%.

A Chinese-Lao company operates as a distributor, supplying bananas to a distribution center in Guangxi Province. Due to privacy concerns, the specific cost and sale price of bananas is not known. However, the distributor obtains an estimated profit margin of approximately 20-30%. It is important to note that the value-added distributions may vary depending on the market channels utilized.

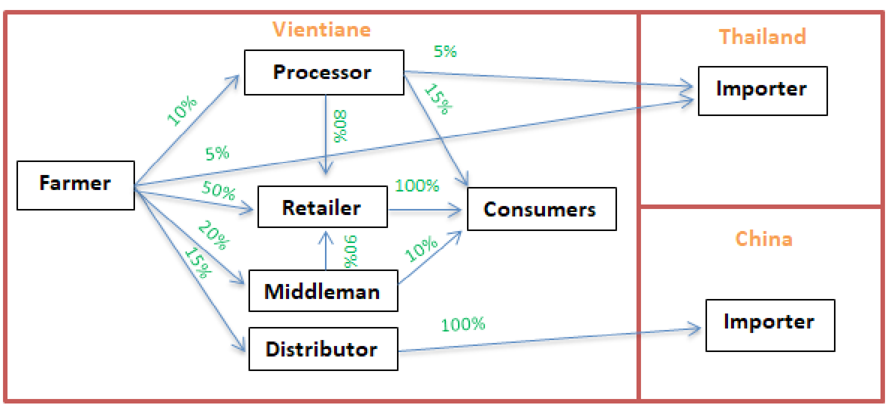

Figure 2. Mapping of value-chain in Vientiane Province.

Value Chain of Cultivated Bananas in Savannakhet

The value chain in Savannakhet Province comprises four key stakeholders: farmers, processors, distributors, and retailers. Farmers play a crucial role in collecting bananas from their farms and selling their products. On average, each household has a farm area of 3.26 hectares, with an average of 2.25 hectares dedicated to banana cultivation. The average total cost of banana production per household per year is 5 million LAK, while the total income from bananas amounts to 7.7 million LAK per household. This results in an approximate profit of 2.7 million LAK per household.

Processors in the province are engaged in producing various banana products, including banana crisps, solar-dried bananas, and dried flattened bananas, which is a unique product in Savannakhet Province. The production process for dried flattened bananas takes two days and requires two workers. On average, processors generate a monthly revenue of 8.4 million LAK, with an average cost of 5 million LAK, resulting in an approximate profit of 3.4 million LAK per household per month.

Distributors, in this case, are Vietnamese companies that purchase bananas from farmers in the Xepon district. They transport the bananas to the Danang seaport in Vietnam and subsequently ship them to China (See Figure 3).

The average profit for farmers is 334 LAK/kg or 32% of the profit margin. For middlemen, the average profit per kg is 542 LAKs or 31% profit margin. Processors have many products from cultivated bananas and those are ripe banana crisp, raw banana crisp, butter banana crisp, and dried flattened banana. The processor makes an average profit of 16,000 LAK/kg or 114% profit margin. The retailers who buy and sell banana products as a vendor make an average profit of 1,000 LAK/pack or a 33% profit margin. Finally, distributors who are the final actor make 500 LAK average profits per kg or 20% profit margin.

Value-chain in Salavan Province

The value chain in Salavan Province involves six key stakeholders, namely middlemen, farmers, retailers, and exporters. Middlemen play a significant role in the value chain by purchasing bananas from farmers in both Savannakhet and Salavan Province. They then sell the bananas to retailers in Savannakhet and Salavan Province. Additionally, middlemen occasionally export products to Thailand. On average, middlemen generate a monthly revenue of 17 million LAK, with a cost of 11 million LAK, resulting in a profit of approximately 6 million LAK per month.

Farmers are responsible for collecting bananas from their farms and selling their products to middlemen and retailers in Salavan and Champasack Province. Each household, on average, possesses a farm area of 6.2 hectares, with an average of 1.9 hectares allocated for banana cultivation. The average total cost of banana production per household per month is 4 million LAK. However, the total income from bananas amounts to 0.8 million LAK per household per month, resulting in a profit of approximately 3.2 million LAK per household per month (See Figure 4).

Farmers in Salavan Province make an average profit of 1,040 LAK/kg or 84% profit margin. Middlemen who collect bananas from farmers make an average profit of 1,009 LAK/kg which creates a 50% profit margin. In Salavan, there are two main types of banana processors, solar-dried banana, and butter banana.

Processors make an average profit of 7,050 LAK/kg or a 34% profit margin. In addition, retailers in Salavan make a profit of 1,200 LAK/kg and create a 67% profit margin. Finally, distributors make a profit of 1,700 LAK/kg or a 94% profit margin. Overall, distributors make up the high-

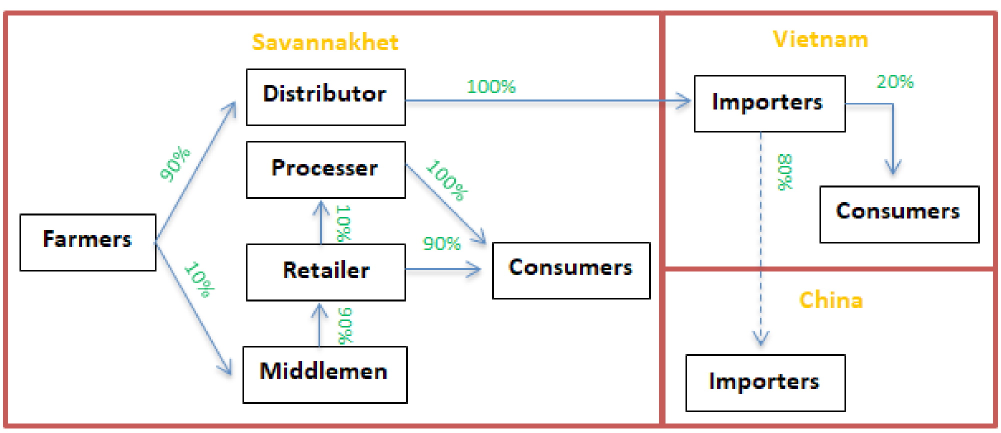

Figure 3. Mapping of value-chain in Savannakhet Province.

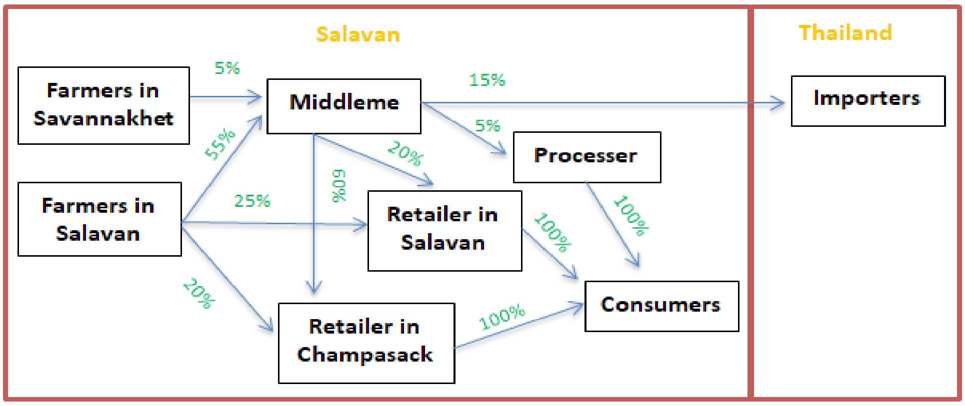

Figure 4. Mapping of value-chain in Salavan Province.

est percentage of profit margin.

3.2 Impact of Cultivated Bananas on Household Income

This section presents the regression results of factors affecting commercialization and the impact of commercialization on income. The summary statistics indicate that there are no outliers in the sample (See Table 3). The correlation matrix shows that there is no multicollinearity issue among the independent variables.

The model of factors affecting banana commercialization shows a very low goodness of fit 0.1049; however, the F-statistic is 11.457 > F-test is 2.78 which means the model is valid. Gender (*Gen*), the age of the head of household (*Age*), education (*Edu*) and distance to the farm (*Df*) did not play any role in banana commercialization (Table 4). The distance to the market (*Dm*), experience (*Exp*) and the number of family members (*Mem*) positively and significantly influenced banana commercialization.

The second stage least squares model was used to examine the impact of commercialization on household incomes. The model shows acceptable goodness of fit. *Gen* and *Edu* are statistically significant at the 5% level. $\hat{C}$ shows statistically significant at a 1% level. *lnK* and *lnS* land area are statistically significant at 0.1% level. However, *Age, Exp* and *P* are statistically insignificant. To ensure the validity of the analysis, various tests including an endogeneity test, instrument test, and over-identification restriction have been conducted. The results confirm the validity of the instrument variable used in the analysis.

Table 3. Summary of statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Commercial	475	0.82	0.10	0.2	0.95
Gender	475	1.24	0.43	1	2
Age	475	42.74	11.04	17	98
Education	475	9.13	2.19	5	16
Experience	475	11.13	7.77	1	40
Policy	475	0.35	0.48	0	1
Labor	475	3.78	2.20	1	25
Cultivated labor	475	2.88	1.30	1	11
Land	475	1.47	2.05	0	24
Capital	475	12,600,000	21,800,000	271,550	53,000,000
Income	475	28,900,000	45,600,000	1,000,000	200,000,000
Market access	475	0.69	0.46	0	1

Table 4. Regression results.

Variable	*C*	*lnI*
Gen	0.002	–0.161*
	(0.21)	(–2.18)
Age	4.76E-05	–0.004
	(0.10)	(–1.84)
Edu	–0.002	0.029*
	(–0.83)	(2.10)
Dm	0.001***	
	(5.53)	
Exp	0.001*	–0.004
	(2.10)	(–0.86)
Df	0.003	
	(1.42)	
Mem	0.009**	
	(2.91)	
lnK		0.259***
		(6.65)
lnL		–0.114
		(–1.52)
lnS		0.237***
		(6.20)
$\hat{C}$		4.259**
		(2.80)
P		0.124
		(1.85)
D2		0.564***
		(3.95)
D3		0.372***
		(3.42)
D4		–0.016
		(–0.12)
Cons	0.697***	9.257***
	(13.90)	(6.91)
R2	0.1049	0.5607
N	475	475

Note: t statistics in parentheses. * < 0.05, ** p < 0.01, *** p < 0.001.

4. Discussions

The value chain of cultivated bananas in four provinces has been significantly driven by the export market. Farmers generate the highest profit, but they receive the lowest distribution of value-added. They face several challenges, including disease and pests that lead to lower yields, limited financial knowledge among farmers for effective management of household income and expenses, and insufficient local market capacity to absorb the banana supply. Cultivated bananas provide a nutritious food source, particularly in areas with limited nutritional options. As organic bananas, there are opportunities to promote them in high-value markets driven by global health concerns.

Processors have the highest value-added potential in the banana value chain. They produce a variety of products from cultivated bananas, such as banana chips, dried bananas, and cakes. The local market has limited processed banana products, creating an opportunity to introduce new products. Processed banana products typically yield higher profit margins than raw bananas. However, processors face some challenges, such as a lack of marketing knowledge, limited product innovation and limited access to funds.

Distributors mainly export raw bananas to Vietnam, Thailand, and China, as demand for bananas has increased in recent years. However, transportation from farms to markets involves multiple inspections, and export procedures require various documents from government offices, resulting in high costs and administrative burdens. The implementation of the dry port in 2021 has further increased the cost and complexity of exporting.

The result of regression suggests that determinants of banana commercialization in Lao PDR include the distance from farm to market, experience, and number of household members. A study found that the coefficient of distance from farm to market (Dm) was positive and significant at the 0.1% level, which means that the farther the distance from farm to market, the higher the rate of commercialization. This is because land rent diminishes from the outward center city to offset both lower revenue and higher operating costs [10]. In Laos, most banana farms are located far from the city (market) where the price of land is low. For example, most bananas in Salavan Province are sold in Champasack Province and exported to Thailand. In the same direction, most bananas produced in Vientiane Province are sold to Vientiane Capital.

Household experience and size are positively associated with the commercialization of bananas. The coefficient of household experience was positive and significant at the 5% level, indicating that an increase in one year of experience leads to a higher commercialization ratio. This suggests that households with more experience in banana cultivation and marketing are more likely to sell a greater quantity of bananas. The coefficient of household size was also positive and significant at the 1% level, suggesting that larger household size is associated with a higher commercialization ratio. This may be because larger households have more labor available to help with banana cultivation and marketing, or because they have more financial resources to invest in banana production.

Banana commercialization can increase the income of farmers, but the impact is not equal for all farmers. A second-stage regression analysis found that gender, education, commercialization, capital, and land are the key factors that impact the income of farmers. The coefficient of gender was found to be negatively significant at the 5% level, indicating that households led by females had lower average incomes compared to households led by males. This could be attributed to factors such as divorce or widowhood, which may lead female-headed households to work harder to earn sufficient income.

Furthermore, the coefficient of education was positively significant at the 5% level, suggesting that higher levels of education were associated with higher household incomes. This finding aligns with previous studies such as Chialue et al. [11], Xangsaysane et al. [12] and Ha et al. [13] that have highlighted the role of education in providing access to information, knowledge, and techniques for increasing income.

The coefficient of predicted commercialization was found to be positive and significant at the 0.1% level, indicating that a 1% increase in banana commercialization resulted in an 8% increase in household income. Bananas were identified as the primary income source for households, and their sustainable income potential was supported by factors such as low production costs, high demand from neighboring countries, and environmentally friendly cultivation practices. The main variables in the income function, including capital and land, demonstrated positive and significant coefficients at the 0.1% level, consistent with production theory.

In contrast, the coefficient of labor was not statistically significant. This can be attributed to the fact that labor is primarily intensive during the plantation phase rather than cultivation. On average, two individuals working for three hours are sufficient to harvest one hectare of bananas.

The coefficient of the policy variable, indicating government support for farmers, was not significant, suggesting that there was no discernible impact of government policies on household income. Most farmers did not receive support from the government of Laos, although some support was provided by organizations such as Japan International Cooperation Agency and The Agrobiodiversity Initiative.

Additionally, the coefficients of the dummy variables D2 and D3 were positive and significant at the 1% level, indicating that average household incomes in Vientiane and Savannakhet Provinces were higher than those in Houaphan Province. However, the coefficient of D4 was not significant, suggesting that the average income of households in Salavan Province did not differ significantly from that of households in Houaphan Province.

5. Conclusions

Numerous studies have raised concerns about the sustainability of Cavendish banana production, citing negative environmental, health, and social impacts despite increased income for farmers. This study analyzes the value chain of cultivated bananas and demonstrates that the commercialization of cultivated bananas can generate sustainable incomes for farmers. The findings reveal significant value-added for farmers, with processors earning the highest value-added but lacking marketing and financial knowledge. Key factors driving commercialization include market access, family members, and experience. The study confirms that the commercialization of bananas leads to increased household income, but questions arise about the long-term sustainability of banana production, particularly given the dependence on demand from neighboring countries.

To address these challenges and promote the sustainable development of cultivated bananas, the following policy implications are recommended:

Farmers should consider creating processed products such as banana cakes, chips, or candies during periods of excess supply or when supply exceeds demand. This approach reduces losses, enhances food security, and improves household nutrition.

Farmers often do not keep track of their income and expenses, which makes it difficult for them to manage their money. Training in basic financial accounting would be very beneficial for households.

The government can help farmers and producers by purchasing their products. For example, banana cake and candy can be used as snacks in schools, as well as during coffee breaks at meetings, seminars, and conferences.

The Ministry of Industry and Commerce (MOIC) should establish exchange programs for farmers and processors, providing training and facilitating the exchange of ideas to create new products. Effective marketing strategies, including attractive packaging and design, can help stimulate sales of processed banana products.

To facilitate distributors, it is better to reduce the number of stops during transportation. This will reduce the cost of transportation for distributors and reduce the risk of damage to bananas during transport.

Villages should initiate activities to promote bananas, such as banana contests or award programs. This will help to raise awareness of bananas and increase demand for them.

Author Contributions

The first author as well as corresponding author Piya Wongpit took the lead in research design, analysis, interpretation as well as writing of the manuscript while co-authors Bounmy Inthakesone, Keuangkham Sisengnam, Pakaiphone Syphoxay support first author in the writing and analysis.

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Data Availability

The data are available upon request from the corresponding author.

Conflict of Interest

The authors disclosed that they do not have any conflict of interest.

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RESEARCH ARTICLE

Cheese Price Softening in the U.S.: Determining Effects from Excessive Cheese in the Market

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Abstract: The United States (U.S.) cheese sector has experienced continuous production and consumption growth since the 1990's with its market characterized as having oligopolistic behavior, signaling that prices respond to supply. Despite the steady industry growth, it experienced a recent multi-year period of declining prices. This paper addresses how growth towards an all-time record surplus of cheese, in response to excess milk production and export drops, weakened U.S. cheese prices. This study finds there is a significant short-run effect on price from overly expanded cheese supply, i.e., specifically taking a 2019 monthly average supply of 2.48 billion pounds, a 10% rise in cheese supply results in an immediate price decrease of 8.7%, translating to an average decline of USD 0.15/pound. The cumulative effect on its price from this 10% change results in a cumulative drop in cheese prices of 18.9%, approximately equal to a decrease of USD 0.34/pound. Findings provide relevant information to cheese, dairy producers and stakeholders, for milk production schedules, risk management and dairy policy analysis.

Keywords: Autoregressive distributed lag model; Cheese prices; Price softening; Supply growth

1. Introduction

The U.S. cheese sector has been steadily growing since the 1990s and has become among the most important commodities in the U.S. dairy agricultural economy. U.S. consumers are consuming twice as much cheese per capita as they did in 1980 [1]. Moreover, annual cheese production in the U.S. has been steadily growing from 6.94 billion lbs. in 1995 [2] to 13.1 billion lbs. in 2019 [3]; with

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supply growth increasing more rapidly in the recent period from 2015 to early 2019 versus the previous five years, i.e. 4.3% annum versus 2.2% annum, respectively. Despite the consumption growth, U.S. cheese markets experienced a steady decline in prices between 2015 and early 2019①. Industry analysts have described the drop in cheese prices as the result from an abundance in the supply of cheese, accompanied by increases in imports and drops in exports. This paper seeks to quantify market effects from an overly abundant growth in cheese supply that weakened its prices, and in turn, affect milk production prices due to milk production pricing mechanisms [4]. The findings of this study enhance our understanding of the relationship between cheese price and its supply, derived from (perishable) milk production, with significant implications for risk management, investment decisions, and potential policy analysis. As a result, agribusiness sectors and supply chain actors involved in cheese markets stand to benefit from this research paper, as it quantifies the impact of excessive growth of cheese supply in the market on both short-run and long-run prices. Moreover, these insights may provide valuable information for strategic decision-making within the cheese industry. Studying the price of cheese holds significant importance, primarily due to the dairy sector's prominent role as the main agricultural industry in several U.S. states, including California, Wisconsin, New York, Idaho, Michigan, and New Mexico, among others. Many of these states are also major cheese producers. In 2021, more than 42% of US milk fat was used for cheese production [5], and the daily consumption of cheese per person increased to 0.74 cup-equivalents (1 cup-equivalent = 1 cup milk) in 2021 from 0.36 cup-equivalents per person in 1981 [6]. Moreover, cheese exports have witnessed growth in recent years, with increased shipments to countries such as Mexico, the Middle East, Japan, Central America, the Caribbean, Korea, Australia, and Colombia in 2022. Hence, as previously mentioned, quantifying the impact of unprecedented growth in cheese supply may assist in providing valuable information for strategic decision-making within the cheese industry.

From U.S. Department of Agriculture (USDA) data, the amount of cheese surplus (beginning stock) in the U.S. grew from about 1 to 1.4 billion pounds between 2016 and 2019 [5], reaching record numbers, as shown in Panel A (highlighted within the blue oval) in Figure 1. The substantial increase in cheese storage began around 2008 in response to milk production exceeding its rates of use/consumption, and driving the milk surplus to produce cheese [7].② Cheese exports have constituted an average of 5.6% of yearly production since 2010. However recently, China and Mexico imposed retaliatory tariffs on U.S. dairy exports in the summer of 2018 as a consequence of a trade war; which resulted in annual cheese shipments dropping by 63% and 10% to China and Mexico; respectively [9]. Between 2010 and 2019 U.S. milk production increased by a total of 13.3% [3], and cheese production grew as well, but at a higher rate of 29.8% (3.3% per annum)—as observed in Panel B in Figure 1. Total cheese supply (sum of stocks, production, and imports) has likewise steadily increased, as shown in Panel C Figure 1, even more in the period 2016 to 2019 (blue oval) as mentioned previously. It is important to note that in 2019, cheese supply growth decreased dramatically as seen in Panel A and Panel C (gold oval).

The increased supply over time has had a notable impact on cheese prices, particularly during the period from 2015 to 2018 as depicted within the blue oval in Figure 2. However, in 2019, cheese prices increased and inventory remained rather steady given the minor cheese production increase of 0.8%, in comparison to 3.1% and 3.8% of the previous two years (Figure 2, yellow oval)③ accompanied by a rise in cheese exports of about 3%. As aforementioned, lower cheese prices also affected dairy producers' milk prices regulated through Federal Milk Marketing Orders (FMMOs), which govern about 75% of the US milk supply [11,12]. The price of cheese plummeted again in the spring of 2020 as the COVID-19 pandemic hit the U.S. (not shown in Figure 2). COVID-19 produced a significant and unexpected shift in cheese demand since a large portion of cheese consumption occurs through restaurants and school cafeterias, and these shut down during the 2nd quarter of 2020 [13]. At the same time, cheese consumption grew in family household cooking settings, though at a lower rate. The shift in consumption outlets as a consequence of the pandemic had varying effects on different agents along the dairy supply chain, as described by Wolf et al. [14].

Cheese prices may be sensitive to supply due to the oligopolistic behavior observed in the structure of the U.S. cheese market, as supported by previous studies by Mueller and Marion [15], Arnade et al. [16], and Bolotova and Novakovic [4]. That is in the classical oligopolistic market model, e.g., the Cournot model, market prices tend to be a function of supply [17]. The empirical strategy employed

① This study does not include price shifts during subsequent period of COVID-19 which is under a different study.

② Milk surplus (oversupply) is noted by average milk production costs being lower than prices; i.e. below perfect competition equilibrium levels [7].

③ In 2019, there was a significant slowdown in year-over-year milk production growth [10].

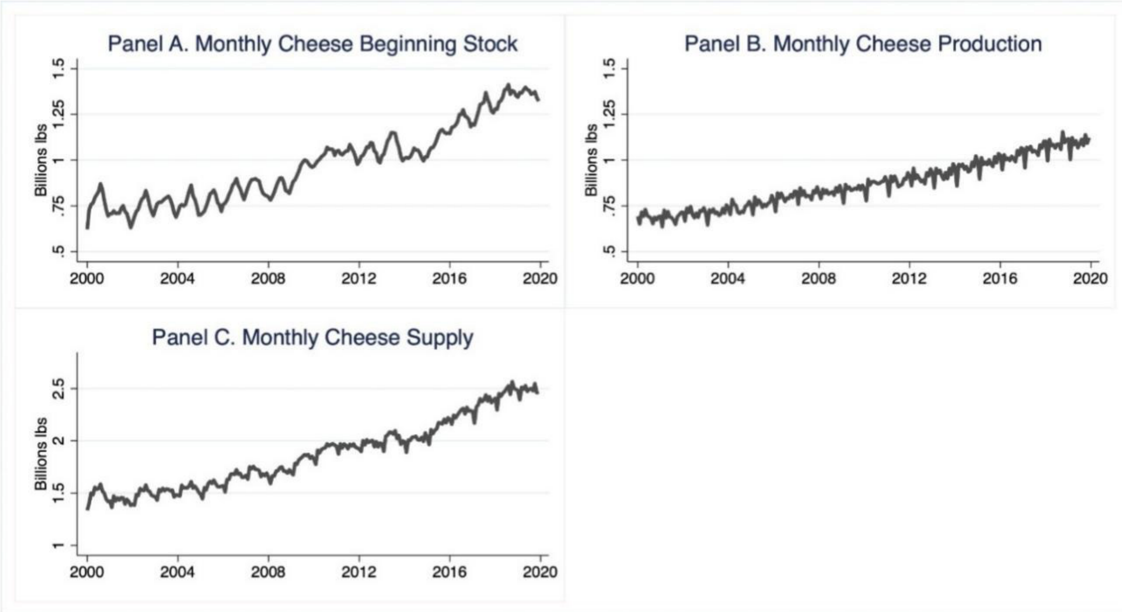

Figure 1. Cheese storage, production, and supply.

Source: Monthly cheese beginning stock (Panel A), production (Panel B) and supply (Panel C) from USDA-ERS [5]. Note that supply in Panel C is the sum of beginning stock, production, and import (not shown here).

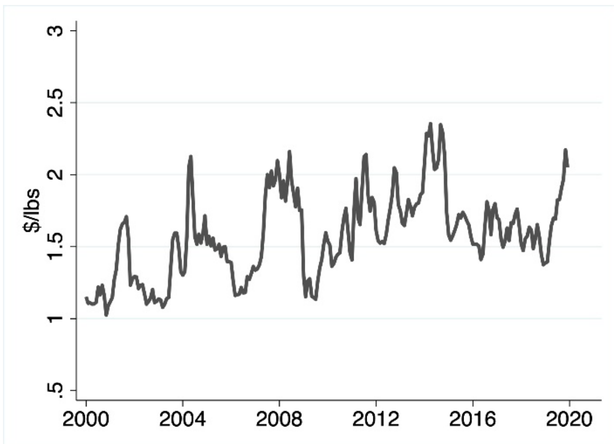

Figure 2. Cheese prices.

Source: Monthly average market prices for cheddar cheese from USDA-AMS (USDA, AMS, 2020b).

in this study is grounded in this theoretical foundation. To provide an intuitive representation of the oligopolistic market structure Figure 3 is presented. In this illustration, the horizontal axis represents the quantity of cheese, q, and the vertical axis represents the cheese price, p. Each point in Figure 3 indicates an equilibrium where supply (S) and demand (D) curves intersect at a specific period in time. Over time, demand and supply curves shift up or down based on supply and demand shifters; for example, milk production affects cheese supply curves and household income influences the cheese demand curves. As a result, multiple supply-demand equilibrium points exist, reflecting different supply-demand interactions over time. The fitted line connecting these equilibrium points represents the long-run relationship (LR) depicted in Figure 3 represents, denoted as $p = f(q)$. Panel A in Figure 3 demonstrates a negative long-run relationship between price and quantity, while Panel B shows a positive relationship. This long-run relationship depends on how supply and demand shift over time. For the period in this study, the growth in cheese supply has outpaced changes in demand, resulting in a negative long-run relationship referred to as "price softening". The theoretical underpinnings and graphical representation provided in Figure 3 help to understand the relationship between cheese price and supply within the context of an oligopolistic market structure.

Market analysts interviewed by financial press suggest that the surge of inventory has depressed prices, despite recent increases in cheese consumption [18]. The hypothesis for this study is taken from these previous assertions, with the primary objective of estimating the market impact from an overly abundance of cheese supply affecting its market price, including the long-run price effect. To date, there has been a research gap in examining the short and long-term implications on cheese price and its variability resulting from the excessive growth of cheese supply. Persistent declines in cheese prices may adversely affect cheese and dairy industry players in the long run, potentially bringing about more industry consolidation [19]. To address this matter, and assume an oligopolistic market

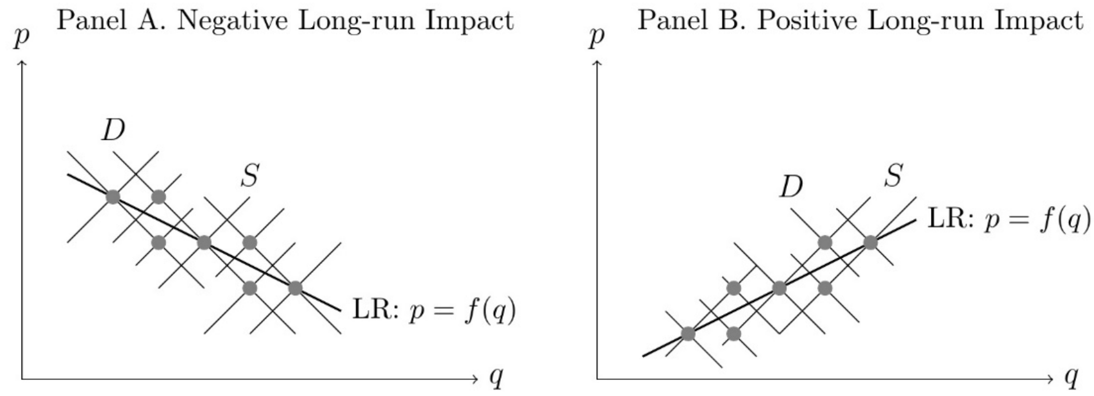

Figure 3. Long-run impact of cheese supply on prices.

Source: Created by authors.

structure, this study employs an autoregressive distributed lag model (ARDL) to estimate price as a function of supply. Taking 2019 as a reference year, empirical results indicate that a 1% increase in cheese supply (equivalent to approximately 24.9 million pounds/month) immediately leads to a 0.87% decrease in cheese prices (approximately 1.5 cents/pound). Moreover, this 1% surge in cheese supply resulted in a 1.89% decrease in prices (roughly 3.4 cents/pound) after a period of six to seven months.

The theoretical implications of this study can be summarized in two key aspects. Firstly, by examining the relationship between cheese supply and prices within an oligopolistic market structure, this study significantly contributes to the theoretical understanding of market dynamics within the cheese industry. As previously mentioned, it shed light on the intricacies of pricing mechanisms and the influence of supply on market outcomes. This analysis augments knowledge of how market forces operate in this specific industry context. Secondly, the findings of this study hold practical significance for policymakers, industry stakeholders, and market participants. The insights gained regarding the impact of cheese oversupply on prices can serve as valuable guidance for better decision-making processes related to supply management, risk mitigation, and investment strategies. By providing empirical evidence and an increased understanding of the dynamics at play, this study supports the formulation of effective policies and aids in informed strategic decision-making within the cheese industry.

The remainder of this study is organized as follows. The next section reviews prior studies that have researched the U.S. cheese market. Section 3 introduces data and examines the (estimated) ARDL model and its pertinence. Results, discussions, and implication remarks follow in Sections 4 and 5.

2. Literature Review

Numerous studies investigating the U.S. cheese sector have addressed matters of cheese markets. Recently Bolotova [20] investigated the spot cheese market and its behavior along different periods of FMMOs finding that this relation has intensified over the years, with increasing effects on price volatility. Tejeda and Kim [21] investigated price dynamics among different cheese varieties finding periods where prices of American and Other cheese types were decoupled. Studies addressing cheese market structure and its oligopolistic nature include Mueller and Marion [15] who examined the trade behavior of leading cheese companies on the National Cheese Exchange, which despite trading less than 0.2% of all cheese sold in the U.S. provided market signals for formula-pricing of 90-95% of all bulk cheese, and found evidence of market manipulation from oligopolistic cheese producers. Arnade et al. [16] investigated the level of retail competition in the U.S. cheese market, finding that the existence of price markups suggested the presence of imperfect competitive behavior. Kim and Cotterill [22] investigated pass-through rates for processed cheese under market conditions and found significant differences in these rates for processed cheese under different market conditions regime in comparison to being under a Nash-Bertrand price competitive regime. For this latter, the pass-through rate was at least three times that of under collusion.

More recently, Bolotova and Novakovic [4] investigated the farm-to-wholesale price transmission process affecting the pricing practices used by Chicago Mercantile Exchange (CME) cheese wholesalers. Findings revealed that pricing strategies used by cheese sellers are consistent with oligopolistic behavior. Lopez et al. [23] determined the level of oligopoly markups above that of being perfectly competitive markets for several U.S. food processing industries by estimating the associated Lerner index, which measures the amount of market power (0 = perfect competition, 1 = monopoly), and found a moderate degree of market power for the cheese manufacturing industry, i.e. corroborating prior results of the presence of oligopolistic behavior. The softening of cheese prices from sizable increases in supply has not been investigated and this study attempts to fill this gap in the literature.

3. Materials and Methods

Monthly average market prices of cheese for the period of January 2000 to December 2019 from the Agriculture Marketing Service (AMS) of USDA for the dairy program are used USDA AMS [24]. Monthly U.S. cheese supply data include production, beginning stock, and imports for the same period and are collected from the Economics Research Service (ERS) of USDA ERS [5]④. Table 1 provides a summary of the data. Cheese supply is the sum of beginning stock, production, and imports (imports not shown in Figure 1). From Table 1, cheese supply is on average 1.87 billion pounds per month (beginning stock 0.98 billion pounds plus production 0.87 billion pounds plus import 0.03 billion pounds) during the sample period, having a consistent upward trend, as shown in Panel C in Figure 1. The average monthly cheese supply during 2018 and 2019 surpassed 2.47 billion pounds after considering the average monthly beginning stock of 1.36 billion pounds. Conversely, the price of cheese displays a relative opposite trend especially from 2015 to early 2019, a period of steady increase in cheese stock. As noted, many market analysts quoted in the business media have expressed concern about cheese prices falling during this period [7,25,26].

The empirical strategy to quantify the impact of unprecedented growth in cheese supply on both short-run and long-run market prices is based on the oligopolistic cheese market structure [4,15]. From prior findings of the U.S. cheese sector depicting an oligopolistic market behavior, it is anticipated that some degree of market power is exerted. In the classical oligopoly market model, e.g., the Cournot model, the market price is a function of total supply [17]. As such, we estimate cheese price as a function of total supply. In addition, the price from a previous period may affect the current price since cheese is a storable commodity, i.e., affecting the adjustment of the supply schedule. To reflect the unique characteristics of the cheese market in the U.S., an innovative approach utilizing an autoregressive distributed lag model (ARDL) considering cointegration [27] is adopted in this study. The ARDL model provides a robust framework for investigating this matter. By employing the ARDL model, we are able to examine both the short-run and long-run relationships between cheese prices and cheese supply, capturing the dynamics of the market over time. An advantage of using the ARDL model with a cointegration approach is that the dependent variable, in this case, cheese prices, is allowed to be non-stationary [28]. Another benefit of using the ARDL model is that through reparameterization we can construct an error correction model, which enables us to find the short-run and long-run effects.

Table 1. Descriptive statistics (Jan 2000-Dec 2019, 240 observations).

Variable	Mean	Std. Dev.	Max	Min
Beginning stock (million lbs.)	976	209	1,413	621
Production (million lbs.)	868	133	1,154	636
Import (million lbs.)	27.2	6.7	46.0	1.4
Supply (million lbs.)	1,871	335	2,567	1,335
Price ($ per lbs.)	1.58	0.98	2.35	1.02

Sources: USDA AMS [24] for cheese prices and USDA ERS [5] for beginning stock, production, and import. Supply is the sum of beginning stock, production, and import.

Applying Kripfganz and Schneider [29], the ARDL (*p, q*) model is expressed by:

$$P_t = c_o + \sum_{i=1}^{p} \phi_i P_{t-i} + \sum_{j=0}^{q} \beta_j S_{t-j} + \varepsilon_t \quad (1)$$

where P_t *is* cheese prices at time *t*, and represented as the sum of lagged cheese prices and the sum of lagged cheese supply, S_t. Both P_t and S_t may be stationary, non-stationary or cointegrated [27,28]. The optimal lags of *p* and *q* are determined by minimizing information criteria such as the Akaike information criterion (AIC) or the Bayesian information criterion (BIC). The error term ε_t is assumed to be serially uncorrelated. Note that ordinary least squares (OLS) is used to estimate model in Equation (1) even though there are lagged dependent variables present on the right-hand side [30]. Pesaran and Shin [28] showed that the OLS estimators of the parameters in Equation (1) are $\sqrt{T}$-consistent and asymptotically normal, in other words, $\sqrt{T}(\boldsymbol{\Phi}, \widehat{\boldsymbol{\Phi}}) \xrightarrow{d} \mathrm{N}(\mathbf{0}, \sigma^2\mathbf{I})$ where $\boldsymbol{\Phi} = [\phi_i, \beta_j]'$.

A trend variable is added to Equation (1) since visual inspection indicates a possible positive trend in cheese prices, as observed in Figure 2. To control for seasonality, 11 monthly dummies are also included in Equation (1). Cheese prices and supply are log-transformed and thus the relationship is in proportional or percentage terms.

The error correction form of the ARDL model can be

④ This study aggregates American and Other-than-American cheese types.

formulated by reparameterization in terms of the lagged levels and the first differences of P_t and S_t [29], and is expressed by:

$$\Delta P_t = c_o - \alpha(P_{t-1} - \theta S_{t-1}) \sum_{i=1}^{p-1} \psi_{pi} \Delta P_{t-i} + \sum_{j=0}^{q-1} \psi_{sj} \Delta S_{t-j} + \varepsilon_t \quad (2)$$

where α is the speed of adjustment (or error correcting) coefficient, defined by:

$$\alpha = 1 - \sum_{i=1}^{p} \phi_i \quad (3)$$

The expression $P_{t-1} - \theta S_{t-1}$ from Equation (2) can be interpreted as the long-run equilibrium denoted by LR, the fitted line, in Figure 3. When cheese prices and/or cheese supply deviates from the long-run equilibrium (LR), cheese prices and/or cheese supply adjust to restore the equilibrium relation at the speed of α. A value of $\alpha \approx 0$ implies a very slow adjustment back to the long-run equilibrium. Thus the value of α measures how fast cheese prices react to a deviation from the long-run relationship, LR. The long-run effects parameter, θ, is computed by:

$$\theta = \frac{\sum_{j=0}^{q} \beta_j}{\alpha} = \frac{\sum_{j=0}^{q} \beta_j}{1 - \sum_{i=1}^{p} \phi_i} \quad (4)$$

Coefficient θ describes the equilibrium effect of supply on cheese prices in the long run. The short-run coefficients, ψ_{pi} and ψ_{sj} in Equation (2) explain the short-run fluctuations not due to deviations from the long-run equilibrium. A value of ψ_{sj} being close to one in absolute terms indicates very rapid price adjustment after a change in cheese supply.

To check for the existence of the long-run relationship in Equation (2), a bounds test is suggested by Pesaran et al. [27]. The null hypothesis is that there is no long-run relationship between cheese prices and cheese supply.

$$H_0^F: \alpha = 0 \text{ and} \sum_{j=0}^{q} \beta_j = 0 \quad (5)$$

If H_0^F is rejected with F-test, a t-test is required to test whether α is zero or not.

$$H_0^t: \alpha = 0 \quad (6)$$

A long-run relationship between the price of cheese and cheese supply may be confirmed by rejecting both previous F-test and t-test. Lastly, the proportion of ψ_{s1} (contemporaneous adjustment) to θ (long-run adjustment) enables to measure the degree of relationship between cheese price and supply, i.e., how much of the price change occurs immediately.

4. Results

Empirical results from estimating Equation (1) for the price of cheese and its supply, between January 2000 and December 2019, are presented. The optimal lags for cheese supply and cheese prices were selected by minimizing BIC resulting in $p = 2$ and $q = 1$. Table 2 presents the top three ARDL models with the lowest BIC for comparison; as mentioned ARDL (2,1) is found to be the preferred resulting model. Note that the bounds test confirms that there is a long-run relationship between the price of cheese and cheese supply (F-stat = 11.79 and t-stat = 7.30; both H^F and H^t from Equations (5) and (6) are rejected at 1% significant level).

The optimal model ARDL (2, 1) from Equation (1) is expressed by:

$$\ln P_t = c_o + \phi_1 \ln P_{t-1} + \phi_2 \ln P_{t-2} + \beta_0 \ln S_t + \beta_1 \ln S_{t-1} + \delta t + \sum_{m=1}^{11} c_m D_m + \varepsilon_t \quad (7)$$

where β_0 is interpreted as the concurrent (instantaneous) supply effect, t is a trend and D_m is a monthly dummy (results are not reported in Table 2 to save space and are available upon request).

The coefficients from Table 2 are not easy to interpret because there are lagged dependent and independent variables. As discussed in the previous method section, a reparameterization of the estimated parameters permits converting the model into an error correction form as in Equation (2), from which estimated results are in Table 3. The long-run coefficient, θ, from Equations (2) and (4) is in the LR row of Table 3, representing the long-run effects of cheese supply on the price of cheese.

The model ARDL (2, 1) from Equation (7) is rewritten in error correction form as follows:

$$\Delta \ln P_t = c_o - \alpha(\ln P_{t-1} - \theta \ln S_{t-1}) + \psi_{p1} \Delta \ln P_{t-1} + \psi_{s1} \Delta \ln S_t + \delta t + \sum_{m=1}^{11} c_m D_m + \varepsilon_t \quad (8)$$

As mentioned, the coefficient of $\Delta \ln S_t$ from Equation (8), ψ_{s1} measures the contemporaneous effect on the price of cheese due to changes in cheese supply. Table 3, $\widehat{\psi_{s1}} = -0.866$ with p-value of 0.02, implies that 1% increase in supply leads to an immediate 0.87% decrease in cheese prices. The estimated value of α, the speed of adjustment coefficient, is –0.164. This suggests that it takes about $\frac{1}{0.16} \approx 6.3$ months to correct an equilibrium disturbance. The estimated parameter, θ, which indicates the long-run effect of an increase in cheese supply on its prices, is –1.891. In other words, a 1% increase in cheese supply results in a 1.89% decrease in cheese prices in the long run. Moreover, the proportion of ψ_{s1} (contemporaneous adjustment) to θ (long run adjustment), $\frac{\hat{\psi}_{s1}}{\hat{\theta}} = 0.46$, which indicates that the immediate change in cheese prices is 46% of the long run change.

5. Conclusions and Implications

The present study seeks to determine the extent that effects from a substantial growth in cheese supply have had on the decline of its prices. This situation not only affects the cheese sector stakeholders but also the milk prices of dairy producers through FMMOs. Previous studies have characterized the cheese market as having an oligopolistic nature, with its prices being a function of supply. Under an oligopolistic market scenario, we make use of monthly cheese prices and supply data from 2000 to 2019 to estimate an ARDL model and quantify the market effects.

Table 2. ARDL model results.

	ARDL (2,0)	ARDL (2,1)	ARDL (3,1)
ln P_{t-1}	1.1357***	1.1224***	1.1686***
	(0.064)	(0.064)	(0.067)
ln P_{t-2}	–0.3086***	–0.2860***	–0.4494***
	(0.065)	(0.065)	(0.099)
ln P_{t-3}			0.1451**
			(0.067)
ln S_t	0.3974**	1.1754***	–1.0991***
	(0.178)	(0.369)	(0.370)
ln S_{t-1}		0.8661** (0.362)	0.8733** (0.359)
Trend	0.0012** (0.0005)	0.0010** (0.0005)	0.0008 (0.0005)
Constant	0.1554**	0.1287**	0.0951
	(0.062)	(0.063)	(0.065)
Obs	238	236	237
Adj R^2	0.878	0.877	0.881
F-stat	114.4[0.00]	105.6[0.00]	103.4[0.00]
BIC	–533.79	–534.56	–534.09

Note: *, **, and *** indicate the significance at 10%, 5% and 1%, respectively.

Results for monthly dummies are not reported to save space, which are available upon request.

P_t represents cheese prices at time t and S_t is cheese supply at time t.

Numbers in brackets in F-stat row are p-values associated with the F-stats.

Empirical results indicate that the recent substantial growth in cheese supply indeed significantly decreased cheese prices. Results from an estimated optimal ARDL (2,1) model find that a 1% increase in cheese supply leads to a 0.87% decrease in cheese prices in the short run and a 1.89% decrease in the long run. That is, for a monthly average supply in 2019 of 2,486 million pounds, a 1% increase in supply is roughly equivalent to 25 million pounds, which would depress cheese prices by 1.53 cents/pound in the short run and 3.32 cents/pound in the long run. Implications from the findings are compelling. Considering 2019 as the reference year, and assuming all other things being equal, if cheese supply had decreased by 7.5% (roughly, 186 million pounds), 2019 cheese prices would have on average been around $2/pound; however, the actual average price was about $1.75/pound.

In conclusion, this study carries important theoretical implications that contribute to our understanding of market dynamics within the cheese industry. By examining the relationship between cheese supply and prices within an oligopolistic market structure, we have shed light on the intricacies of pricing mechanisms and the influence of excessive supply growth on market outcomes. This analysis enriches our knowledge of how market forces operate within this specific industry context. Moreover, the practical implications of our findings hold significant relevance for policymakers, industry stakeholders, and market participants. The insights gained from this study regarding the impact of the unprecedented growth of cheese supply on prices provide valuable guidance for decision-making processes related to supply management, risk mitigation, and investment strategies. Empirical evidence and a deeper understanding of the dynamics at play can inform the formulation of effective policies and facilitate informed strategic decision-making within the cheese industry. It is crucial to note that discussions surrounding cheese prices should consider the unusual and significant growth in cheese supply, as revealed in this study. Such considerations have implications for risk management and trade policy analysis. By incorporating these insights, stakeholders can navigate challenges posed by the mentioned cheese supply phenomena studied and make well-informed decisions to foster a viable and sustainable cheese sector.

There are several potential avenues for future research based on the findings and implications of this study. Firstly, while this study primarily focused on the impact of the unprecedented growth of cheese supply on prices, future research could expand on this by examining the role of demand factors in shaping cheese prices. Investigating the relationship between consumer preferences, demographic

Table 3. ARDL in error correction form.

		ARDL (2,0)	ARDL (2,1)	ARDL (3,1)
ADJ	$\ln P_{t-1}$	–0.1730***	–0.1636***	–0.1357***
		(0.035)	(0.035)	(0.037)
LR	$\ln S_t$	–2.2980***	–1.8910**	–1.6636
		(0.839)	(0.914)	(1.141)
SR	$\Delta\ln P_{t-1}$	0.3086***	0.2860***	0.3043***
		(0.065)	(0.065)	(0.065)
	$\Delta\ln P_{t-2}$			–0.1451**
				(0.067)
	$\Delta\ln S_t$		–0.8661**	–0.8733**
			(0.362)	(0.359)
	Trend	0.0012**	0.0010*	0.0008
		(0.0005)	(0.0005)	(0.0005)
	Constant	0.1554**	0.1266*	0.0951
		(0.062)	(0.064)	(0.065)

Note: *, **, and *** indicate the significance at 10%, 5% and 1%, respectively.

Results for monthly dummies are not reported to save space, which are available upon request.

ARDL (p, q) represents autoregressive distributed lag model; p is number of lags of autoregressive terms, P_{t-i}, and q is number of distributed lag terms, S_{t-j}. See Equation (1).

ADJ represents α, the speed of adjustment, in Equation (3).

LR represents θ, the long run coefficient, in Equation (4).

SR represents ψ_{pi} and ψ_{sj}, the short run coefficients, in Equation (2).

changes, and market demand could provide a more comprehensive understanding of the dynamics of price formation in the cheese industry. Secondly, further research could delve into the broader implications of supply chain efficiency and coordination on market outcomes. Factors such as transportation costs, inventory management, and distribution strategies can significantly impact the overall functioning of the cheese market. Exploring these aspects can provide insights into how supply chain dynamics affect price dynamics and market outcomes. Thirdly, considering the growing export market for cheese, future research could explore the impact of international trade on domestic cheese prices and market integration. Analyzing trade patterns, tariffs, and trade agreements can offer valuable insights into the relationship between global market dynamics and domestic cheese prices.

Lastly, it is important to address a caveat. This study assumed an oligopolistic market structure in the cheese industry based on previous studies [4,15,16]. However, it is essential to acknowledge that market structures may evolve over time, and the assumption of an oligopoly in the U.S. cheese market may no longer be the case. Future research could investigate the current market structure and its implications for price dynamics to provide updated insights.

Authors Contributions

The authors confirm contribution to the paper as follows: study conception and design: Z. Wang, H. Tejeda, and M-K. Kim; data collection: Z. Wang and W. Siu; analysis and interpretation of results: Z. Wang, H. Tejeda, M-K. Kim and W. Siu; draft manuscript preparation: Z. Wang, H. Tejeda, M-K. Kim and W. Siu. All authors reviewed the results and approved the final version of the manuscript.

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Data Availability

Data is available upon request (all the data used in the manuscript are available from the public domain). Please contact the corresponding author.

Conflict of Interest

Authors certify that we have no affiliation with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

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RESEARCH ARTICLE

Impact of Farmer Producer Organizations on Price and Poverty Alleviation of Smallholder Dry Chillies Farmers in India

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Abstract: This study investigates the impact of Farmer Producer Organizations (FPOs) on smallholder dry chilli farmers in Guntur district, Andhra Pradesh, with a focus on price realization and poverty alleviation. Two specific FPOs, Red Chilli Farmer Producer Organisation and Spoorthi Chilli Producers Company Ltd., from the Guntur district of Andhra Pradesh were chosen for the study based on their substantial business turnover and comprehensive backward and forward linkages to their farmer-members. The smallholder farmers were stratified into two groups viz., treated (161) and untreated (n = 315) based on the FPO membership criterion. The Foster-Greer-Thorbecke model revealed that the poverty incidence among untreated farmers was recorded at 0.691, which was approximately 49 percent higher than the poverty incidence of treated farmers (0.352). The depth and severity of poverty were also greater among untreated farmers, with a poverty depth of 0.494 compared to the lower value of 0.126 observed among treated farmers. The results from Endogenous Switching Regression Model revealed a significant positive relationship between FPO membership and both price realization and poverty alleviation. Farmers with FPO membership experienced 2.11 percent higher prices and 39.14 percent higher annual agricultural income compared to untreated. Factors such as education, adherence to Good Agricultural Practices, farm experience, access to improved inputs, and credit significantly influenced FPO membership. The study concludes that FPO membership plays a crucial role in improving the standard of living for smallholder dry chilli farmers by increasing prices and income. So, this research sheds light on the significance of FPOs in enhancing the economic well-being of smallholder dry chilli farmers in Andhra Pradesh.

Keywords: Farmer producer organizations; Andhra Pradesh; Endogenous switching regression model; Impact assessment; Transitional heterogeneity

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1. Introduction

In India, the agriculture sector currently contributes approximately 13.39 percent to the Gross Domestic Product (GDP) while employing about 55 percent of the total workforce, indicating its significant role in the economy. As per the Agricultural Census of 2015-2016, there were over 145 million farm holdings in the country. Notably, marginal and small farm holdings constituted a substantial proportion, accounting for 86.21 percent of the total indicating the dominance of small-scale farmers in the agricultural landscape [1]. The share of small and marginal holdings has experienced a slight increase from 84.97 percent in 2010-2011 to 86.21 percent in 2015-2016, amounting to approximately 126 million holdings. This trend indicates a gradual decline in per capita land size over the past five years, primarily attributed to land subdivision and fragmentation. These have contributed to the persistence of poverty in the country leading to a decline in crop productivity, inefficient resource allocation, limited access to credit, the prevalence of subsistence farming, land disputes etc. [2]. The recent estimates revealed that approximately 10.2 percent of the population, or around 145.71 million people, were living Below Poverty Line (BPL) (www.scroll.in (10th June 2023)) and the percentage of the total population living BPL in Andhra Pradesh was 12.31 percent (https://www.newindianexpress.com, 10th June 2023). In view of these, alleviating poverty among farmers is crucial for ensuring food security, promoting rural development, stabilizing the economy, reducing overall poverty, fostering social stability, and pursuing sustainable development goals. The formation of Farmer Producer Organizations (FPOs) can significantly contribute to poverty alleviation among farmers by promoting collective action, enhancing market access, improving access to credit, fostering knowledge sharing, and advocating for policy reforms. Thus, they help farmers improve their income, enhance productivity, mitigate risks, and build sustainable agricultural enterprises, ultimately leading to improved living standards and reduced poverty among farming communities [3,4].

The XII Plan Working Group (formed as part of India's Five-Year Plans) associated with the policy of FPOs in India emphasized that small and marginal farmers encounter significant challenges in both production and marketing within the agri-business sector. These challenges include low output, limited marketable surplus, inadequate participation in price discovery mechanisms, weak vertical and horizontal linkages, restricted market access, lack of price information, insufficient training, and limited access to finance. Among these challenges, the issue of market access is particularly prominent among smallholder farmers [5]. Hence, the current imperative lies in optimizing benefits through effective and efficient aggregation models, especially by integrating these smallholders into agricultural markets. Such a transformation would lead to a more market-oriented agricultural production system, economies of scale, and higher income for smallholder farmers, ultimately resulting in more inclusive growth.

In this context, one of the significant interventions promoted by the Government of India is the Farmer Producer Company (FPC), which is registered under the Companies Act. FPCs have emerged as the most effective form of FPOs in providing various benefits to farmer-members compared to other aggregation formats such as cooperative societies and Farmer Interest Groups. Ministry of Agriculture and Farmers Welfare, Government of India, has identified FPOs registered under the special provisions of the Companies Act, 1956 (amended in 2002) and the Companies Act, 2013, as the most suitable institutional form for aggregating farmers. Forming a FPC under the Companies Act, 2013 facilitates capacity building among farmers, encourages them to work together, share knowledge and resources, and learn from each other's experiences. This will mobilize farmers towards member-owned FPOs to enhance production, productivity, and profitability across the country [6]. This initiative aims to empower farmers and enable them to access better market opportunities and improve their overall socio-economic well-being (Figure 1).

Dry chillies are a significant crop cultivated on 0.73 million hectares in India during 2020-2021 [1]. Among the States, Andhra Pradesh ranked first in dry chilli production during the same period [7]. Guntur, located in Andhra Pradesh, is renowned as Asia's largest market for dry chillies. The Agricultural Produce Market Committee (APMC) in Guntur receives dry chillies from various production regions in Andhra Pradesh as well as from Madhya Pradesh. Notably, the production trends in Madhya Pradesh significantly impact the prices of dry chillies in the Guntur market. Guntur district holds a comparative advantage over other districts due to factors like labor availability, specialization, mechanization, and irrigation facilities. Enhancing dry chilli productivity is crucial for promoting farmers' profitability and development in this region. To support this objective, the Government of Andhra Pradesh has facilitated the establishment of six FPOs that specifically focus on dry chillies in Guntur district. However, the production of dry chillies in Guntur predominantly relies on smallholder farmers, who constitute 92 percent of the total number of farmers in the region. These small-scale farms face challenges in both production and marketing of

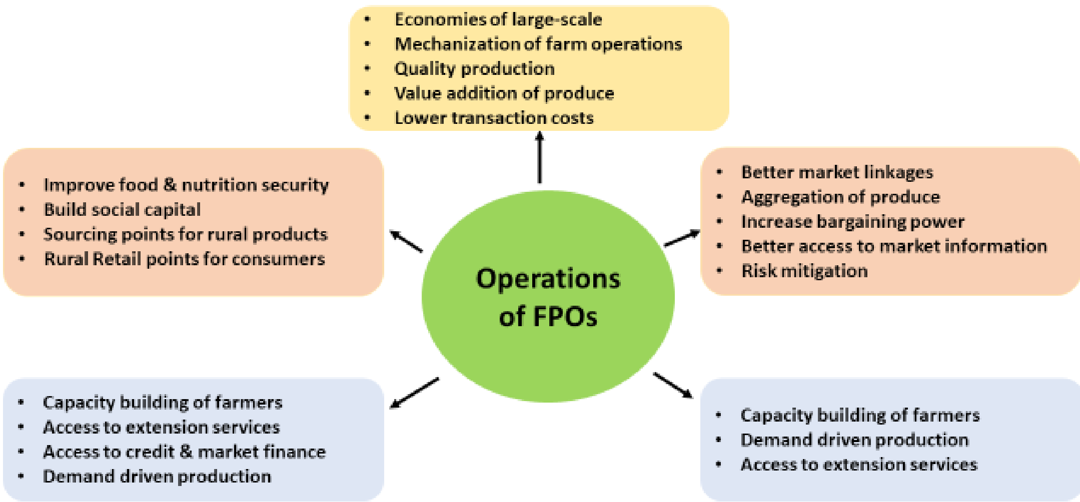

Figure 1. Operations of FPO.

their produce [7]. Previous studies on FPOs have primarily focused on aspects like the growth of farmer-members, establishment of linkages, transaction volumes, and prices realized for the produce [8-10]. However, these studies have not provided a comprehensive assessment of the overall impact of FPOs. Therefore, this study aims to contribute to the existing literature by delving into the factors that drive smallholder dry chillies farmers' decision to engage with FPOs. It seeks to examine socio-economic characteristics, resource accessibility, market linkages, and institutional support as determinants of farmers' participation. By analyzing these factors, the research can offer valuable insights into the factors influencing farmers' involvement in collective agricultural initiatives. Furthermore, the study seeks to assess the impact of FPOs on the achievement of remunerative prices and poverty alleviation among smallholder farmers. This analysis holds significance in the literature on collective marketing initiatives, providing insights into their role in improving farmers' income and overall economic well-being.

2. Review of Literature

The studies examined in the review collectively showcase the transformative potential of FPOs on farmers' livelihoods, productivity, and sustainability. These findings underscore the need for a comprehensive approach to agricultural development, integrating various interventions and leveraging diverse agricultural models.

Ranjit et al. (2022) [9] emphasized that FPOs offer substantial promise for small and marginal farmers in India. Through effective collective action, FPOs empower farmers, enhance market access, and reduce transaction costs. However, addressing the capital constraints faced by FPOs remains a significant challenge. Policy-makers must prioritize the development of enabling environments, including improved access to finance, capacity-building support, and institutional reforms, to fully unlock the potential of FPOs. This will pave the way for inclusive and sustainable agricultural development, elevating the livelihoods of small and marginal farmers and fostering overall rural prosperity.

In the study by Manaswi [11] et al. (2020), the benefits of FPOs in organic chilli production are underscored. FPO membership is associated with higher gross returns, reduced transaction costs, and increased technical efficiency. These findings highlight the importance of collective action, improved market linkages, and streamlined value chains through FPOs, enabling farmers to secure better prices and access to markets.

Barun and Sunil [12] (2019) shed light on the impact of improved agricultural practices on farm productivity. They emphasize the significance of public-private partnerships in promoting practices such as seed distribution, bio-fertilizer production, and capacity-building. These partnerships, which combine technical knowledge, resources, and infrastructure, facilitate the adoption of sustainable farming practices. As a result, farmers experience increased productivity and resilience in the face of challenges like climate change.

John et al. (2019) [13] explore the relationship between contract farming and chilli productivity in Ghana. Their study reveals that contract farming has a positive effect on productivity and gross margins. Educated farmers, larger farm sizes, and integrated soil fertility management are identified as factors influencing contract farming participation. This suggests the need to target and support educated farmers, enabling them to engage in contract farming and potentially improve productivity and market access.

In the dairy sector, Anjani et al. (2018) [14] highlight the positive effects of cooperative membership on milk yield, net return, and adoption of food safety measures. Cooperative membership provides farmers with improved infrastructure, technology, and collective marketing opportunities. These benefits contribute to increased income and the adoption of practices that ensure food safety and quality.

Wondimagegn (2016) [15] explores the impact of improved storage innovations on food security and welfare. The study demonstrates that households using improved storage technologies enjoy higher dietary diversity scores, indicating improved access to a variety of nutritious foods. This underscores the significance of appropriate storage practices in preserving agricultural produce, reducing post-harvest losses, and enhancing food security.

Lastly, Tamer et al. (2015) [16] focus on the impact of zero tillage on the livelihoods of smallholder farmers. Their study highlights the benefits of conservative tillage, including increased net income and per capita wheat consumption. Conservative tillage practices improve soil health, water retention, and crop productivity while minimizing environmental degradation. Promoting these sustainable agricultural practices enhances farmers' livelihoods and contributes to broader ecological benefits.

Taken together, these studies demonstrate that a combination of approaches, including the formation of FPOs, adoption of improved agricultural practices, engagement in contract farming, participation in cooperatives, and implementation of innovative technologies, can significantly improve farmers' incomes, productivity, and sustainability. These findings underscore the importance of integrating multiple interventions tailored to the local context, addressing the complex challenges faced by farmers, and promoting inclusive and resilient agricultural systems.

3. Materials and Methods

3.1 Data and Research Method

In the initial stage of the study, the state of Andhra Pradesh and Guntur district were purposefully chosen based on their potential for dry chillies production and the presence of a significant number of functioning FPOs involved in its production and marketing (Figure 2). In the second stage, two specific FPOs, namely Red Chilli Farmer Producer Organisation located in Machavaram mandal and Spoorthi Chilli Producers Company Ltd located in Edlapadu mandal, were purposively selected. These FPOs were chosen due to their substantial business turnover and their ability to provide comprehensive backward and forward linkages to their farmer-members. Two sampling frames were created, one consisting of the lists of farmer-members from the two selected FPOs (treated group) and the other consisting of non-members (untreated group). So, farmers in the study area were then stratified into treated and untreated groups based on their FPO membership status. In the third stage, smallholder dry chilli farmers were selected in proportion to the number of farmers in each stratum based on probability proportional to the number sampling technique. This ensured that the selected sample of farmers in Guntur was representative and included both treated (n = 161) and untreated (n = 315) categories based on the FPO membership criterion. A structured schedule was employed to gather the required cross-section data from sample farmers on covariates and outcome variables, as shown in Table 1, specifically related to the Kharif season of 2022-2023. Prior to the actual survey, the schedule underwent a pre-testing phase in non-sampled villages to assess the suitability and effectiveness of the schedule in gathering the required data and to evaluate the proficiency of the enumerators in conducting the survey. The collected comprehensive data sought to provide a holistic understanding of the farmers' socio-economic context and their engagement in various agricultural practices. Further, to analyze the impact of FPO membership on poverty alleviation, only farmers who derived their annual income solely from agricultural sources were included in the sample. This criterion ensured that the analysis focused on smallholder chilli farmers whose livelihoods primarily relied on agriculture. This sampling approach and data collection process allowed for a comprehensive examination of the impact of FPO membership on poverty alleviation among smallholder chilli farmers in the study area.

3.2 Tools of Analysis

a. Descriptive statistics: Descriptive statistics viz., mean and Standard Deviation (SD) are employed to analyze and compare the selected variables between treated and untreated farmers.

b. Estimation of Poverty Profile (Foster-Greer–Thorbecke (FGT) Model): As per the FGT model [17], the poverty profile of the sample farmers is represented below:

$$P_{(\alpha)} = (1/n) \sum_{i=1}^{q} \{(y_p - y_i)/y_p\}^{\alpha} \quad (1)$$

where 'n' is the number of sample farmers (households), 'y_i' is the income of the i^{th} household, 'y_p' represents the poverty line indicated by the income limit for households qualifying as a beneficiary under the BPL (ie., ≤ Rs.1,20 lakh per year for rural households in Andhra Pradesh (https://www.business-standard.com), 'q' is the number

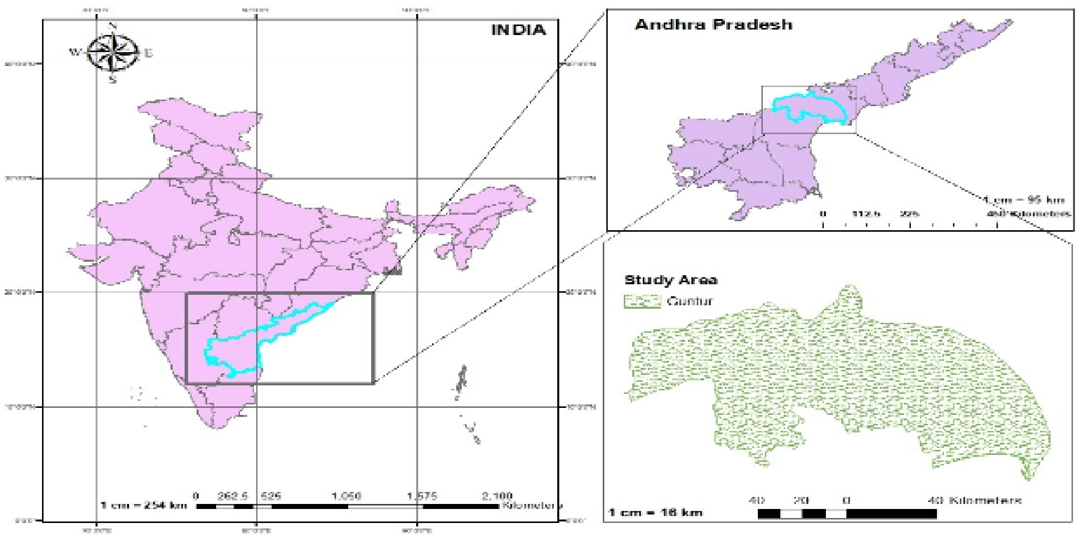

Figure 2. Selection of Guntur district, Andhra Pradesh.

Table 1. Variable types and definitions.

Variable type	Abbreviation	Variables definition
Outcome Variables	Price	Price realized for dry chillies (Rs./quintal of produce transacted)
	Poverty	BPL is indicated by the income limit for households ie., ≤ Rs.1,20,000/year for rural households in Andhra Pradesh* - Primary data regarding annual income derived by both treated and untreated farmers from dry chillies transactions are considered.
Treatment variable	FPO membership decision	FPO membership/Dummy (1 = Member, 0 = Non-member)
Instrumental Variable (IV)	MOTIV	Motivation of farmers to join in FPOs/Dummy (1 = Yes, 0 = No)
Covariates	GND	Gender/Dummy (1 = Male, 0 = Female)
	LHS	Landholding size (Acres)
	EDU	Education of the farmer/Dummy (1 = Yes if > 10th class, 0 = No, if < 10th class)
	GAP	Good Agricultural Practices/Dummy (1 = Yes, 0 = No)
	FE	Farming Experience (years)
	DTF	Distance to FPO from village (kilometers)
	AMI	Access to market information/Dummy(1 = Yes, 0 = No)
	AII	Access to improved inputs at right time/Dummy (1 = Own land, 0 = No)
	ATE	Access to extension services/Dummy (1 = Yes, 0 = No)
	ATIV	Access to improved dry chillies varieties/Dummy (1 = Yes, 0 = No)
	ATIC	Access to institutional credit/Dummy (1 = Yes, 0 = No)

* https://www.thehindu.com/news/national/andhra-pradesh/andhra-pradesh-to-raise-incomelimit-for-bpl-category/article30098727.ece

of households BPL, and 'α' is the poverty parameter (incidence, gap and severity) which takes the values of 0 (P measures poverty head count ratio), 1 (P measures the depth of poverty), and 2 (P measures severity or intensity of poverty).

c. ESRM approach: In this study, the potential endogeneity issue of FPO membership influencing farmer participation is addressed using the ESRM [18]. To verify the exogeneity of the endogenous variable (FPO membership), both the Durbin score test and Wu-Hausman test for endogeneity are conducted. To account for self-selection bias in the decision to join FPOs, the study incorporates a selection equation with MOTIV (a relevant variable) as an instrumental variable for FPO membership. This approach helps address the endogeneity concern by using an instrumental variable that affects FPO membership but is not directly related to the outcome variable of interest. The selection equation used in this study follows the framework [19] as specified below:

$$e_i^* = X_{i\alpha} + \delta_i \text{ with } M = \{1 \text{ if } M^* > 0; = 0 \text{ otherwise}\} \quad (2)$$

For a farmer-member of FPO (M = 1), if M∗ > 0, where M∗ represents the expected benefits of participating in FPO (treated) compared to untreated. The analysis of the impact of FPO membership on the outcome variables (prices and poverty) under the ESRM framework proceeds in two stages. In the first stage, a probit model (Equation 3a) is used to analyze the determinants of the decision to join FPO. In the second stage, an OLS regression with selectivity correction is employed to study the relationship between the outcome variables and a set of explanatory variables, conditional on the FPO membership decision (Equation 3b). The two outcome regression equations, conditional on FPO membership, can be expressed as [16]:

Regime 1 (Treated): $y_{1i} = x_{1i}\beta_1 + \varepsilon_{1i}$ if, M = 1 (3a)

Regime 2 (Untreated): $y_{0i} = x_{0i}\beta_0 + \varepsilon_{0i}$ if, M = 0 (3b)

where, y_{1i} and y_{0i} are the outcome variable(s) with and without FPO membership respectively, x_{1i} and x_{0i} are vectors of exogenous covariates; β_1 and β_0 are vectors of parameters; and ε_{1i} and ε_{0i} are random disturbance terms. The error terms are assumed to have the following covariance matrix:

$$cov(\varepsilon, \epsilon_1, \epsilon_0) = \begin{bmatrix} \sigma_{\epsilon 0}^2 & \sigma_{\epsilon 1 \epsilon 0} & \sigma_{\epsilon 0 \varepsilon} \\ \sigma_{\epsilon 1 \epsilon 0} & \sigma_{\epsilon 1}^2 & \sigma_{\epsilon 1 \varepsilon} \\ \sigma_{\epsilon 0 \varepsilon} & \sigma_{\epsilon 1 \varepsilon} & \sigma_{\varepsilon}^2 \end{bmatrix} \quad (4)$$

where σ_{ε}^2 is the variance of the selection equation (Equation 4), $\sigma_{\epsilon 0}^2$ and $\sigma_{\epsilon 1}^2$ are the variances of the outcome equations for untreated and treated, while $\sigma_{\epsilon 0 \varepsilon}$ and $\sigma_{\epsilon 1 \varepsilon}$ represent the covariance between, ϵ_1 and ϵ_0 [20]. If ε is correlated with ϵ_1, and ϵ_0, the expected values of ϵ_1, and ϵ_0 conditional on the sample selection are non-zero:

$$E(\epsilon_1 | \mathrm{M} = 1) = \sigma_{\epsilon 1 \varepsilon} \frac{\phi(Z_i \beta_i)}{\Phi(Z_i \beta_i)} = \sigma_{\epsilon 1 \varepsilon} \lambda_1 \quad (5)$$

$$E(\epsilon_0 | \mathrm{M} = 0) = \sigma_{\epsilon 0 \varepsilon} \frac{-\phi(Z_i \beta_i)}{1 - \Phi(Z_i \beta_i)} = \sigma_{\epsilon 0 \varepsilon} \lambda_0 \quad (6)$$

where, ϕ and Φ are the probability density and the cumulative distribution function of the standard normal distribution, respectively. The Full Information Maximum Likelihood (FILM) estimator is used to fit an ESRM to compare the actual expected outcomes of treated (Equation 7) and untreated (Equation 8), and to investigate the counter factual hypothetical cases that the untreated did participate in FPO (treated) (Equation 9) and the treated did not participate in FPO i.e., untreated (Equation 10) as follows:

$$E(y_1 | \mathrm{M} = 1) = X_1 \beta_1 + \sigma_{\epsilon 1 \varepsilon} \lambda_1 \quad \text{-----> (a)} \quad (7)$$

$$E(y_0 | \mathrm{M} = 0) = X_0 \beta_0 + \sigma_{\epsilon 0 \varepsilon} \lambda_0 \quad \text{-----> (b)} \quad (8)$$

$$E(y_0 | \mathrm{M} = 1) = X_1 \beta_0 + \sigma_{\epsilon 0 \varepsilon} \lambda_1 \quad \text{-----> (c)} \quad (9)$$

$$E(y_1 | \mathrm{M} = 0) = X_0 \beta_1 + \sigma_{\epsilon 1 \varepsilon} \lambda_0 \quad \text{-----> (d)} \quad (10)$$

In the above equations and Table 2, cases (a) and (b) represent the actual expectations observed in the sample, and cases (c) and (d) represent the counter factual expectations with respect to prices and poverty alleviation.

Following [21-23], the ATT and ATU are calculated as below:

$$ATT = \mathrm{E}(y_{1i} | \mathrm{M} = 1; x) - \mathrm{E}(y_{0i} | \mathrm{M} = 1; x), = x_{1i}(\beta_1 - \beta_0) + \lambda_{1i}(\sigma_{\varepsilon 1} - \sigma_{\varepsilon 0}) \quad (11)$$

$$ATU = \mathrm{E}(y_{1i} | \mathrm{M} = 0; x) - \mathrm{E}(y_{oi} | \mathrm{M} = 0; x), = x_{2i}(\beta_1 - \beta_0) + \lambda_{2i}(\sigma_{\varepsilon 1} - \sigma_{\varepsilon 0}) \quad (12)$$

$$\mathrm{BH}_1 = \mathrm{E}(y_{1i} | \mathrm{M} = 1; x) - \mathrm{E}(y_{1i} | \mathrm{M} = 0; x) = (x_{1i} - x_{2i})\beta_{1i} + \sigma_{\varepsilon 1}(\lambda_{1i} - \lambda_{2i}) \quad (13)$$

$$\mathrm{BH}_2 = \mathrm{E}(y_{2i} | \mathrm{M} = 1; x) - \mathrm{E}(y_{2i} | \mathrm{M} = 0; x) = (x_{1i} - x_{2i})\beta_{2i} + \sigma_{\varepsilon 2}(\lambda_{1i} - \lambda_{2i}) \quad (14)$$

Conditions in Equations (11) to (14) can be described as follows:

- The treatment on treated (A*TT*) is the difference between (7) and (9), which is given by Equation (11).
- The effect of the treatment on untreated (A*TU*) is the difference between (10) and (8), which is given by Equation (12).
- The effect of heterogeneity of treated (BH_1) is the difference between (7) and (10).
- The effect of base heterogeneity (BH_2) of untreated is the difference between (9) and (8).

By comparing the results of Equations (13) and (14) or (11) and (12), the Transitional Heterogeneity (TH) is estimated [24]. TH represents the heterogeneity in the effect of FPO participation, indicating whether the effect is larger or smaller for the farmers who actually participated compared to the counter factual scenario where non-participants hypothetically participated. This analysis allows for a deeper understanding of the nuanced impacts of FPO participation, considering the differential effects treated and untreated. It sheds light on the potential variations in outcomes and helps identify factors that may influence the differential effects of FPO participation among farmers.

4. Results and Discussion

4.1 Descriptive Statistics of the Variables

According to the results presented in Table 3, both treated and untreated farmers, with respect to FPO membership, exhibit similar averages in terms of variables such as LHS, FE, and DTF. However, when it comes to other covariates, treated farmers demonstrate statistically significant advantages over untreated farmers. Specifically, treated farmers who are members of the FPO benefit in terms of both prices and annual income compared to their untreated counterparts, and these differences are statisti-

Table 2. Treatment and heterogeneity effects.

TH	Decision stage		Treatment effects
	Treated	Untreated	
Treated	$E(y1i\|M = 1) = (a)$	$E(y0i\|M = 1) = (c)$	ATT (a – c)
Untreated	$E(y1i\|M = 0) = (d)$	$E(y0i\|M = 0) = (b)$	ATU (d – b)
Heterogeneity effects	BH1 (a – d)	BH2 (c – b)	TH (ATT – ATU)

Notes: (a) and (b) represent observed expected outcome indicators, (c) and (d) represent counter factual expected outcome indicators; M = 1 if farmers participate in FPO and M = 0, otherwise; y_{1i}: Outcome indicators if farmers participate in FPO, y_{0i}: Outcome indicators if farmers do not participate in FPO; ATT: effect of the treatment (i.e., FPO membership) on the treated, ATU: Effect of the treatment (i.e., FPO membership) on the untreated; BH_1: The effect of base heterogeneity for farmers enjoying membership in FPO (M = 1), BH_2: The effect of base heterogeneity for farmers not having membership in FPO (M = 0), TH = (ATT – ATU) [14].

cally significant. The advantages enjoyed by treated farmers can be attributed to various factors facilitated by FPO membership, such as economies of large-scale production, reduced transaction costs, and better market linkages. These factors contribute to higher prices obtained by treated farmers, which in turn leads to higher annual income compared to untreated farmers. These results suggest that FPO membership provides tangible benefits to farmers, including improved prices for their produce and increased annual income, as a result of factors associated with FPOs such as economies of scale, reduced transaction costs, and enhanced market connections [25,26].

4.2 Poverty Analysis—Estimation of Poverty Status among Smallholder Dry Chilli Farming Households

The Below Poverty Line (BPL) classification is a recognized benchmark used to indicate economic disadvantage and identify households in need of Government assistance and aid. In the Indian context, the poverty line is determined based on household income rather than the level of prices. Recently, the Government of Andhra Pradesh has revised the income limit for the BPL category, setting it at an annual income below Rs. 1.20 lakh

Table 3. Descriptive statistics of the variables across Treated vis-à-vis Untreated.

Variables	Pooled (n = 476)		Treated (n = 161)		Untreated (n = 315)		'Z' test (Treated – Untreated)
	Mean	SD	Mean	SD	Mean	SD	
Price (Rs/qtl)	8221.73	271.87	8943.72	150.82	7457.56	149.05	7.23**
Income (Rs/year)	125092.60	54985.57	141068.8	46120.05	96482.62	32589.32	11.94**
FPO membership	0.3382	0.4736	--	--	--	--	--
GND	0.3634	0.4815	0.8634	0.3445	0.1079	0.3108	23.93**
LHS	3.3277	0.9877	3.6273	0.8520	3.1746	1.0180	1.82
EDU	0.3866	0.4875	0.6460	0.4797	0.2540	0.4360	7.66**
GAP	0.5609	0.6074	0.7019	0.4589	0.4889	0.6598	3.41*
FE	24.3466	11.6288	23.9068	11.6075	24.5714	11.6517	0.83
DTF	25.0231	15.1344	25.5031	14.8409	24.7778	15.2998	0.2459
AMI	0.3971	0.4898	0.9441	0.2304	0.1175	0.3225	9.4502**
AII	0.3761	0.4849	0.6534	0.4994	0.2365	0.4733	2.6102**
ATE	0.2311	0.4220	0.9621	0.2421	0.3175	0.4662	9.4907**
ATIV	0.4223	0.4944	0.8261	0.3802	0.2159	0.4121	19.58**
ATIC	0.5609	0.4968	0.7516	0.4335	0.3635	0.4995	2.09*

Note: ** and * denote significance levels at 1% and 5% levels respectively.
Raw data source: Field survey, 2022-2023.

for rural families. In the study's context, smallholder dry chilli farmers whose household income falls below this BPL threshold are considered to be living in poverty. This classification enables the identification of farmers who are economically disadvantaged and require targeted support and interventions. By considering the BPL category, the study aims to assess the impact of FPO membership on poverty alleviation among these smallholder farmers.

The findings from Table 4 reveal significant insights into the extent and severity of poverty among smallholder dry chilli farmers in the study area. The calculated poverty indicators shed light on the challenges faced by these farmers and emphasize the importance of targeted interventions and policies to improve their economic well-being. Firstly, the study area's poverty incidence (P0) of 0.521 indicates that approximately 52 percent of the sample farmers are living in BPL. This high percentage highlights the prevalence of poverty in the region and the urgent need to address this issue. Secondly, the poverty depth or gap (P1) of 0.23 indicates that, on average, the income of poor households falls short by 23 percent of the poverty line. This statistic demonstrates the extent of income inadequacy faced by poor farmers and the magnitude of the challenge in lifting them out of poverty. Figure 2 visually represents the proportion of the poverty line that needs to be bridged to uplift these poor farmers' incomes above the poverty line. Moreover, the poverty severity (P2) rate of 16.6 percent highlights the existence of a subgroup among the poor population that experiences particularly severe poverty. These farmers are in dire need of attention from policy-makers, and measures such as income redistribution and livelihood improvement initiatives should be prioritized to uplift their standard of living. These poverty indicators provided by this study offer valuable data for policy-makers to develop targeted interventions and policies that address the economic challenges faced by smallholder dry chilli farmers in the study area. FPO membership has been identified as a significant positive factor in improving the farmers' standard of living by increasing prices and income [27,28].

Table 4. Estimates of poverty incidence, depth and severity among smallholder dry chilli farmers.

Category	Incidence (P0)	Depth (P1)	Severity (P2)
Treated	0.352	0.126	0.059
Untreated	0.691	0.494	0.281
Overall	0.521	0.226	0.166

Raw data source: Field survey, 2022-2023.

According to Figure 3, the poverty profile analysis highlights the stark disparities between untreated and treated farmer-households, indicating that FPO membership has a significant impact on poverty and economic conditions. The study reveals that untreated farmer-households had a substantially higher poverty incidence of 0.691 compared to treated farmer-households, where the poverty incidence was significantly lower at 0.352. This 49 percent difference in poverty incidence suggests that a larger proportion of untreated farmers were living below the poverty line compared to their treated counterparts. Moreover, the depth and severity of poverty were also found to be greater among untreated farmers. The poverty depth for untreated farmers was measured at 0.494, indicating a larger income shortfall below the poverty line for this group. In contrast, treated farmers had a lower poverty depth of 0.126, implying a comparatively smaller income deficit. Similarly, the severity of poverty was 0.281 for untreated farmers, while treated farmers experienced a much lower severity of poverty at 0.059. This significant difference indicates higher levels of inequality and deprivation among untreated farmers. The study's findings are consistent with previous research [27,29]. In the context of the current study, these results strongly suggest that membership in FPOs and the associated benefits, such as economies of scale, reduced transaction costs, and improved market linkages, play a vital role in poverty reduction and decreased income inequality among smallholder dry chilli farmers in the study area.

4.3 ESRM Approach

Before proceeding with the ESRM, the variables were tested for the presence of multicollinearity. The estimated Variance Inflation Factor (VIF) values for all the variables in both the price and poverty models were found to be less than the critical value of 10 (Appendix 1). This indicates that multicollinearity was not a problem [30-32]. The absence of multicollinearity suggests that the variables are not highly correlated with each other, and their independent contributions can be effectively assessed. To test for heteroskedasticity, the Breusch-Pagan/Cook-Weisberg test was conducted on both models. The findings indicated the absence of heteroskedasticity, indicating that the variances of the error terms in the models were constant (Appendix 2). The overall test of possible endogeneity of the 'FPO membership' variable produced significant results in both the price and poverty models (Table 5). The findings of both the Durbin (score) χ^2 (1) test and the Wu-Hausman F (1,462) test were significant, implying that the treatment variable, 'FPO membership' is highly endogenous in both models. This means that the decision to join FPO is influenced by other factors, and endogeneity needs to be

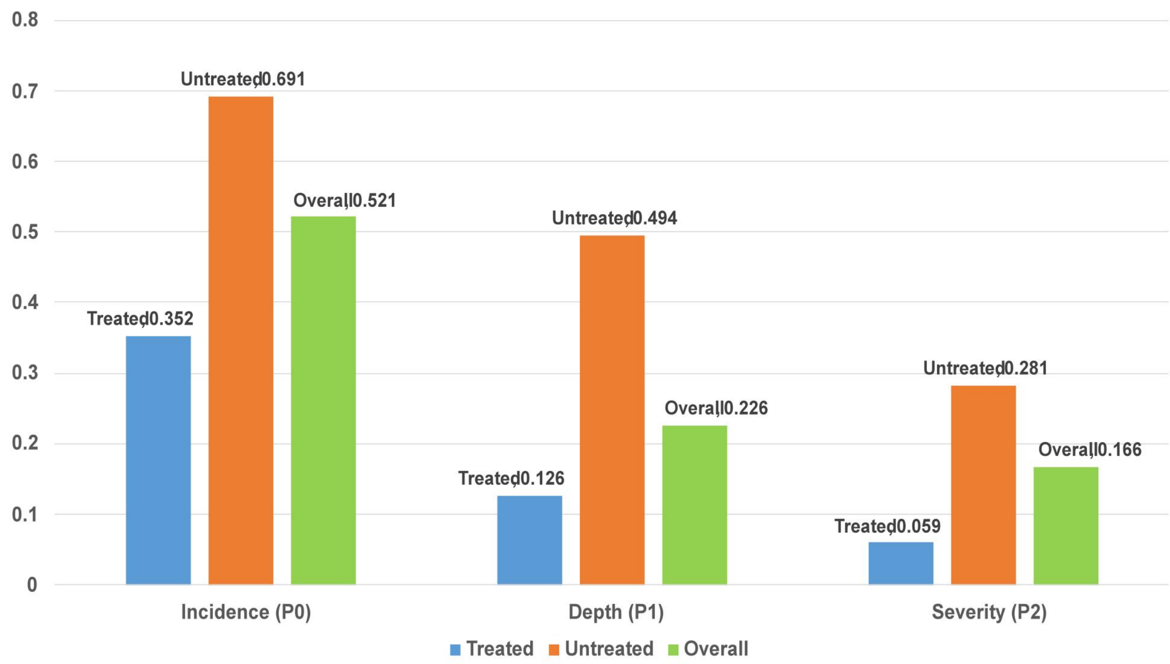

Figure 3. Poverty incidence, depth and severity among smallholder (dry) farmers.

controlled for in the estimation process to obtain unbiased results. These tests and findings help ensure the reliability and validity of the estimation process in addressing the impact of FPO membership on both prices and poverty outcomes among smallholder dry chilli farmers.

Table 5. Tests for the endogeneity of 'FPO membership' variable in price and poverty models.

S.No	Models	Durbin (score) χ^2 (1)	Wu-Hausman F (1,462)
1	Price	13.5524 (0.0002)	13.5393 (0.0003)
2	Poverty	16.3384 (0.0001)	16.4215 (0.0001)

Raw data source: Field survey, 2022-2023.

Tables 6 and 7 present the Wald χ^2 test statistics for the price and poverty models, respectively, indicating that both models exhibit a good fit for the ESRM. This suggests that the ESRM framework is appropriate for addressing the endogeneity problem and obtaining reliable estimates for the study. To further investigate the endogeneity issue, the researchers conducted a Likelihood Ratio (LR) test to test the independence of the outcome and selection equations. The LR test results show that the null hypothesis (HO) of 'no correlation between FPO membership and price/income across both the price and poverty models' was rejected, as evidenced by the test statistics of 19.27** and 17.66** respectively. This rejection indicates that there is a positive correlation between FPO membership and price/income in both the outcome and selection equations, and thus, these equations are dependent on each other. The positive correlation between FPO membership and price/income in both outcome and selection equations is a strong indication of endogeneity, meaning that FPO membership is not randomly assigned but influenced by other factors. This highlights the need to account for endogeneity in the model specification for both the price and poverty models to obtain more accurate and unbiased estimates. By identifying and addressing the endogeneity issue through the ESRM approach, the study ensures that the estimated impact of FPO membership on price realization and poverty alleviation is more reliable and robust. It allows policy-makers and researchers to have confidence in the findings and better understand the true relationship between FPO membership and the economic well-being of smallholder dry chilli farmers in the study area. The Full Information Maximum Likelihood (FIML) approach is a powerful statistical method used in this study to jointly estimate both the outcome and selection equations. This approach allows the researchers to account for the endogeneity issue and obtain reliable estimates of the impact of FPO membership on prices and poverty outcomes for smallholder dry chilli farmers. In Tables 6 and 7, the outcome equations are presented in columns 2 and 3, respectively. These equations represent the estimated impact of FPO membership on price realization and poverty for both the treated and untreated categories of farmers. By analyzing these outcome equations, the study can quantify the specific effects of FPO membership on prices and poverty levels, taking into consideration the FPO membership status of the farmers. Column 4 in Tables 6 and 7 presents the selection equation. This equation identifies the determinants of FPO membership, allowing the researchers to understand the factors influencing farmers' decisions to join or not join the FPOs. The estimated impact of FPO membership based on the coefficients of the OLS regression is presented in the last column (column 5) of Tables 6 and 7. To provide a comprehensive understanding of the impact of FPO membership, the study employs the ESRM framework, which simultaneously estimates the

Table 6. ESRM-Impact of FPO membership on price realization of smallholder dry chilli farmers.

Dependent Variable ------→	Endogenous switching regression			OLS
	Treated (Price)	Untreated (Price)	FPO membership (Treated = 1 Untreated = 0)	Price
1	2	3	4	5
FPO membership				0.0283** (0.0061)
MOTIV	--	--	0.3879** (0.1088)	--
GND	0.0046 (0.0030)	0.0002 (0.0140)	0.0257 (0.0652)	–0.0079 (0.0047)
LHS	0.0297** (0.0076)	0.0004 (0.0034)	0.2647** (0.1043)	0.0095* (0.0045)
EDU	0.0125* (0.0059)	0.0027 (0.0084)	0.2170* (0.1009)	0.0029 (0.0021)
GAP	0.0128** (0.0048)	0.0056 (0.0056)	0.0309** (0.0115)	0.0052 (0.0034)
FE	0.0151** (0.0053)	0.0001 (0.0002)	0.0244* (0.0112)	9.79E-06 (0.0002)
DTF	–0.0101** (0.0032)	–0.0074** (0.0022)	–0.2751** (0.1043)	–0.0209** (0.0047)
AMI	0.0490** (0.0095)	0.0653** (0.0132)	0.3032** (0.1021)	0.0497** (0.0062)
AII	0.0064** (0.0016)	0.0027 (0.0038)	0.0448** (0.0161)	0.0002 (0.0048)
ATE	0.0118** (0.0021)	0.0533** (0.0096)	0.3689** (0.1389)	0.0154** (0.0056)
ATIV	0.0266** (0.0066)	0.0115** (0.0028)	0.4458** (0.1887)	–0.0002 (0.0001)
ATIC	0.0181** (0.0066)	–0.0139 (0.0081)	0.1721 (0.0963)	–0.0006 (0.0046)
Constant	3.1927 (0.0192)	3.2348 (0.0157)	0.5922 (0.3167)	3.2353 (0.0099)
σ_i	0.0639** (0.0031)	0.0561** (0.0066)		
ρ_j	–0.4897** (0.2025)	0.8987 (0.8705)		
n	476			476
Wald χ^2 (11)	194.67** (0.0000)			
LR test of independent equations: χ^2 (1)	19.27** (0.0000)			

Note: Robust standard errors in parentheses; ** & * indicate 1 and 5 percent probability levels respectively.

Raw data source: Field survey, 2022-2023.

outcome and selection equations, accounting for the endogeneity problem. This approach takes into account the interdependencies between the decision of farmers to join the FPO and the resulting outcomes on prices and poverty levels [33-35]. These estimates allow the researchers to draw meaningful conclusions about how FPO membership affects price realization and poverty alleviation among smallholder dry chilli farmers.

In the price model (Table 6), the covariance term of FPO membership for the treated category is statistically significant (–0.4897**), indicating that self-selection occurs in FPO membership. This means that treated farmers

Table 7. ESRM-impact of FPO membership on poverty alleviation of smallholder dry chilli farmers.

Dependent Variable ------→	**Endogenous switching regression**			**OLS**
	Treated (Poverty)	**Untreated (Poverty)**	**FPO membership (Treated = 1 Untreated = 0)**	**Poverty**
1	**2**	**3**	**4**	**5**
FPO membership				0.4897** (0.0251)
MOTIV			0.3956** (0.1290)	
GND	–0.0288 (0.0221)	–0.0063 (0.0221)	0.1352 (0.7812)	0.0280 (0.0187)
LHS	0.2815** (0.0119)	0.3555** (0.0307)	0.2234** (0.0366)	0.3363** (0.0061)
EDU	0.0713* (0.0335)	–0.0195 (0.0158)	0.6835** (0.2794)	0.0221 (0.0132)
GAP	0.0163** (0.0052)	0.0144 (0.0105)	0.3079* (0.1504)	0.0139 (0.0098)
FE	0.0021** (0.0006)	0.0003 (0.0009)	0.0108** (0.0013)	0.0032** (0.0005)
DTF	–0.0033** (0.0007)	–0.0025** (0.0004)	–0.0193* (0.0091)	–0.0006 (0.0004)
AMI	0.0208** (0.0047)	0.0613** (0.0266)	0.4349** (0.0406)	0.0067** (0.0006)
AII	0.0347** (0.0015)	0.0205 (0.0231)	0.3330** (0.0914)	0.0112 (0.0138)
ATE	0.0399** (0.0148)	0.0411* (0.0203)	0.0587** (0.0195)	0.0406** (0.0163)
ATIV	0.0256** (0.0083)	0.1111** (0.0179)	0.3835** (0.1129)	0.0063 (0.0146)
ATIC	0.0580* (0.0279)	–0.0054 (0.0146)	0.7203* (0.3305)	0.0073 (0.0146)
Constant	11.0260 (0.0951)	10.2932 (0.0318)	4.3691 (0.7417)	10.3616 (0.0288)
σ_i	0.1235** (0.0075)	0.1182** (0.0047)		
ρ_j	–0.4661* (0.2309)	0.2262 (0.2416)		
n	476			476
Wald χ^2 (11)	618.73** (0.0000)			
LR test of independent equations: χ^2 (1)	17.66** (0.0000)			

Note: Robust standard errors in parentheses; ** & * indicate at 1 and 5 percent probability levels respectively.

Raw data source: Field survey, 2022-2023.

who choose to have FPO membership may have different effects compared to untreated farmers. The negative and significant sign of ρ_j for the treated category suggests a positive bias. This means that farmers with above-average prices have a higher probability of enjoying FPO membership. On the other hand, the insignificant covariance estimate for the untreated category (0.8987^{NS}) suggests that, in the absence of FPO membership, there would be no significant difference in the average price realized between the treated and untreated categories due to unobservable factors. These estimates are consistent since $\rho_1 < \rho_2$. Therefore, farmers who are members of FPOs are able to obtain higher prices compared to their untreated counterparts, as reported in studies [12-14]. Similar findings are observed in the poverty model (Table 7), where the covariance term of the treated category is statistically significant (–0.4661**), indicating a positive bias. The covariance estimate for the untreated category is insignificant (0.2262^{NS}). This suggests that treated farmers realize higher incomes than they would if they did not have FPO membership [36]. The estimated coefficient of correlation (ρ_j) is statistically significant for the treated category in both models, indicating the presence of sample selectivity bias in both equations. So, the H_O that *sample selectivity bias was absent in both equations* can be rejected [37]. Moreover, there is a significant difference in σ_i across the treated and untreated categories, indicating the presence of heterogeneity in the sample. In both models, ρ_1 and ρ_2 have alternative signs, with ρ_1 being statistically significant and negative, while ρ_2 is statistically non-significant and positive. This suggests that farmers decide whether to join FPOs based on comparative advantages. The significance of ρ_1 indicates that self-selection matters and farmers with above-average price and income levels have higher chances of enjoying FPO membership. Therefore, treated farmers experience better or higher prices and incomes than they would without FPO membership. Furthermore, the positive value of ($\sigma_1 - \sigma_2$) term (i.e., between treated and untreated) across both models demonstrates that participating in FPO membership ensures higher prices and incomes under self-selection than under random assignment. These results confirm that the ESRM is an appropriate model controlling for self-selection and inherent differences between the treated and untreated categories, as discussed by Seng [20].

The differences in the significance of coefficients of the key explanatory variables in both ESRMs (Tables 6 and 7) provide valuable insights into the presence of heterogeneity [21]. In the price model (Table 6), for the treated category (column 2), an increase in EDU and adherence to GAPs in dry chilli cultivation significantly increase the price of the produce. However, for the untreated category (column 3), these variables do not show a correlation with price, and even their magnitudes are lower compared to the treated category. This pattern is similarly observed in the poverty model concerning the realization of higher income across the treated and untreated categories. The results indicate that a higher level of education plays a significant role in influencing prices and incomes among smallholder dry chilli farmers who are members of FPOs. Education facilitates better access to local extension networks, leading to FPO membership, and subsequently, access to backward and forward linkages, higher productivity, increased output, and substantial benefits compared to the untreated category. Hence, EDU and GAPs together contribute to higher prices and incomes in the Guntur district. Importantly, the coefficients in Tables 6 and 7 represent unconditional effects, and the observed differences are not solely due to FPO membership. Additionally, it is evident that EDU and GAPs play a joint role in determining the likelihood of participating in FPOs and influencing the outcome variables (price and income). These findings align with previous works [12,16,23,15,20]. Factors such as FE, AII, and ATIC also exhibit heterogeneous effects between the treated and untreated categories across both price and poverty models. This variation is expected as long-term farm experience influences farmers' membership in FPOs and their access to quality inputs for dry chilli production. Regarding ATIC, the untreated category primarily relies on non-institutional loans from local wholesalers, millers, and private money lenders, resulting in the sale of their produce in local markets, unlike the treated farmers. In contrast, treated farmers, benefiting from higher prices and prompt payment of sales proceeds, are considered more creditworthy by institutional sources. Hence, FPO membership plays a crucial role in enhancing the repayment capacity of treated farmers, highlighting the link between credit and marketing through FPO membership. Furthermore, the variable "LHS" is found to significantly increase both price and income for the treated farmers and significantly influence income for the untreated category. On the other hand, "DTF" negatively and significantly influences price and income, as the remoteness of farms discourages farmers' membership in FPOs, leaving them deprived of remunerative prices compared to the treated category. These findings reveal the presence of heterogeneity in the effects of key explanatory variables between treated and untreated categories in the price and poverty models.

In the selection equations (column 4), the major drivers for farmers' membership in FPOs include MOTIV, LHS, EDU, GAP, FE, AII, AMI, ATE, and ATIV. The instrumental variable "MOTIV" stands out as having a positive and significant influence on both the price (0.3879**) and poverty (0.3956**) models. This result is not surprising, as farmers who have strong linkages with research and extension networks are motivated to join FPOs. This finding is in line with earlier research [14] and thus, provides valuable evidence that MOTIV plays a crucial role in influencing FPO membership and contributes to poverty alleviation by increasing income above the poverty line of Rs. 1.20 lakh per year. Consistent with theoretical expectations, several other factors also show significant effects on FPO membership and subsequent outcomes. Farmers with more farm experience, access to improved inputs, extension agents, improved dry chilli varieties, and market information achieve significant increases in prices and income. However, it is noteworthy that "DTF" has a significant negative influence on farmers' membership in FPOs. This implies that the remoteness of farms discourages farmers from joining FPOs, potentially limiting their access to benefits such as higher prices and improved income that FPO members enjoy. On the other hand, the variable "GND" does not show a significant influence on the outcome variables, in line with the findings from previous studies [38,39].

The last column (OLS approach) of Tables 6 and 7 focuses on examining the effects of FPO membership on price and poverty alleviation. The results indicate a significant difference in the prices and incomes realized between the treated and untreated categories of FPO membership. However, it is crucial to acknowledge that the OLS approach assumes that "FPO membership" is exogenously determined, whereas in reality, it is endogenously determined, as demonstrated in Table 5. The endogeneity of FPO membership can introduce bias in the OLS estimates, as there might be unobservable factors that simultaneously influence both FPO membership and the outcome variables (price and income). Consequently, the OLS estimates may not provide accurate and reliable estimates of the true causal effects of FPO membership on the outcomes. To address this endogeneity issue and obtain unbiased and consistent estimates, the study employed ESRM in the second, third, and fourth columns of Tables 6 and 7. This model allows for the control of endogeneity by incorporating instrumental variables (MOTIV) to disentangle the true causal effects of FPO membership on price and poverty alleviation from confounding factors, resulting in more reliable and robust estimates.

Treatment Effects: The ESRMs results on the expected outcomes under actual and counter factual conditions for treated and untreated are shown in Table 8. A simple comparison of observed outcomes of treated and untreated alone can be misleading [16], as it suggests that on average the treated (a) farmer's price and income are 2.28 and 5.79 percent respectively higher than the untreated (b). However, the correct comparison is between the observed outcomes for treated (a) and the counter factual case (c), which shows that by having membership in FPO, the treated are earning on average 2.11 percent higher price than if they had become untreated. Similarly, comparing the expected price in the counter factual case (d) and observed outcome (b), by not having membership in FPO, untreated are forgoing 1.25 percent of the price. That is, the untreated would have received a higher price by 1.25 percent if they had become treated. These results indicate that FPO membership has a significant positive impact on the prices realized by the treated farmers compared to the untreated farmers. This is further supported by the TH effect, which is positive for prices, indicating that the effect of FPO membership is even greater for the treated farmers compared to the untreated farmers [40,41].

Table 8. Treatment and heterogeneity effects.

	Treated	**Untreated**	**Treatment effects**
Price			
Treated	(a) 3.2934	(c) 3.2253	TT = 0.0681**
Untreated	(d) 3.2601	(b) 3.2199	TU = 0.0402**
Heterogeneity effects	BH_1 = 0.0333	BH_2 = 0.0054	**TH = 0.0279****
Poverty			
Treated	(a) 16.0723	(c) 11.5511	TT = 4.5212**
Untreated	(d) 13.8569	(b) 11.4114	TU = 2.4455**
Heterogeneity effects	BH_1 = 2.2154	BH_2 = 0.1397	**TH = 2.0757****

Raw data source: Field survey, 2022-2023.

Furthermore, in terms of income, the comparison between the observed outcomes for the treated farmers (a) and the counter factual case (c) shows that by being a member of an FPO, the treated farmers earn, on average, 39.14 percent higher annual income compared to what they would have earned if they were untreated. Similarly, comparing the expected income in the counter factual case (d) and the observed outcome (b) for the untreated farmers, it is found that the untreated farmers are forgoing 21.43 percent of annual income by not being members of an FPO. In other words, the untreated farmers would have received a 21.43 percent higher income if they had chosen to become treated. These results indicate that FPO membership significantly increases the income realized by the treated farmers compared to the untreated farmers. The TH effect is also positive for income, indicating that the effect is even greater for the treated farmers compared to the untreated farmers [39].

Overall, the results from both the price and poverty models, as indicated by the TH effects, demonstrate that farmers who enjoy membership in an FPO have realized higher prices and incomes at a significant level compared to untreated farmers at both decision stages. Therefore, the sources of heterogeneity suggest that treated farmers obtain higher prices and incomes than untreated farmers regardless of their participation status. In other words, farmers who have FPO membership are still better off than those who are non-members.

5. Conclusions and Policy Implications

The agriculture sector plays a significant role in the Indian economy, contributing approximately 13.39 percent to the GDP and employing 55 percent of the total workforce. However, small and marginal farmers, who constitute a majority of the farming population, face various challenges such as low output, limited marketable surplus, inadequate market access, and lack of access to credit and training. These challenges contribute to poverty and hinder the development of the agricultural sector. To address these issues, the Government of India has promoted the formation of FPOs as a means to alleviate poverty among farmers. In the case of dry chilli production in Guntur, Andhra Pradesh, smallholder farmers face challenges in both production and marketing. To support these farmers, the government has facilitated the establishment of six FPOs specifically focused on dry chillies in Guntur district. The participation of smallholder farmers in these FPOs has provided them with numerous benefits, including economies of scale, strengthened market linkages, access to quality inputs and extension services, reduced transaction costs, enhanced bargaining power, and access to remunerative prices for their produce. However, previous studies on FPOs have primarily focused on growth, linkages, transaction volumes, and prices, without providing a comprehensive assessment of the overall impact of FPOs. Therefore, this study aims to fill that gap by examining the factors driving smallholder dry chilli farmers' decision to engage with FPOs. Moreover, this study assesses the impact of FPOs on the attainment of remunerative prices and poverty alleviation among smallholder farmers. The analysis focuses on the state of Andhra Pradesh and Guntur district, considering their potential for dry chillies production and the presence of functioning FPOs in the region. Two specific FPOs, Red Chilli Farmer Producer Organisation and Spoorthi Chilli Producers Company Ltd, were selected for an in-depth study. The study utilized cross-sectional data consisting of 161 treated farmers (FPO members) and 315 untreated farmers (non-members) randomly selected. To address potential endogeneity issues, the study utilizes the Endogenous Switching Regression model, which incorporates a selection equation with a relevant instrumental variable. This approach helps account for self-selection bias in the decision to join FPOs and provides a robust analysis of the impact of FPO membership on poverty alleviation among smallholder chilli farmers. The empirical results of the ESRM analysis revealed a positive and significant association between FPO membership and both price realization and poverty alleviation. Specifically, FPO membership was found to increase prices by 2.11 percent and annual agricultural income by 39.14 percent. Several factors were identified as major drivers of farmers' participation in FPO membership, including EDU, GAP, FE, AII, ATIC, LHS, DTF, AMI, ATE and ATIV. These factors influenced both the price and poverty models. The negative signs of the parameter (ρ_j) for the treated group in both the price and poverty models indicate a positive bias, suggesting that farmers with above-average prices and income are more likely to join FPOs. Furthermore, the comparison of parameters ($\rho_1 < \rho_2$) indicates that farmers with FPO membership achieved higher prices and annual income compared to those who remained untreated. Based on the findings, the study concludes that FPO membership contributes to an improved standard of living for smallholder dry chilli farmers by increasing prices and income compared to non-members. The positive impact of FPO membership on prices and income can have long-term beneficial effects and potentially extend to other aspects of farmers' lives. Therefore, it is recommended that the Government promote the popularity of FPOs among farmers. Initiatives such as the Agriculture Infrastructure Fund (AIF) Scheme and linking FPOs to the electronic National Agriculture Market (e-NAM) portal provide ample opportunities to promote and support FPOs. By creating awareness, providing financial support, and facilitating market access, policy-makers can encourage more farmers to join FPOs and reap the benefits of collective action and market integration.

Author Contributions

K. Nirmal Ravi Kumar: conceptualization, review, methodology, data collection, data curation, data analysis, writing initial draft; M. Jagan Mohan Reddy: expert comments and suggestions; Adinan Bahahudeen Shafiwu: expert comments and suggestions; A. Amaraendar Reddy: expert comments and suggestions. All the authors have read and agreed to the published version of the manuscript.

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Data Availability

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest

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Appendices

Appendix 1. VIF among selected independent variables.

Variables	VIF	1/VIF
FPO membership	1.39	0.7190
AMI	2.33	0.4293
GND	2.19	0.4561
ATE	1.41	0.7113
ATIV	1.4	0.7133
LO	1.36	0.7337
ATIC	1.3	0.7663
EDU	1.23	0.8155
MOTIV	1.12	0.8909
LHS	1.08	0.9223
GAP	1.07	0.9305
DTM	1.04	0.9632
FE	1.02	0.9824

Appendix 2. Breusch-Pagan/Cook-Weisberg test for heteroskedasticity.

	Price	Income (Poverty)
χ^2 (1)	0.09	0.13
Prob (χ^2)	0.7625	0.7178

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RESEARCH ARTICLE

An Analysis of Agribusiness Digitalisation Transformation of the Sub-Saharan African Countries Small-Scale Farmers' Production Distribution

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Abstract: The article aims to analyse how digitalisation transforms the marketing and distribution of produce by small-scale sub-Saharan African agribusiness. Small-scale farmers reside in remote areas where market information is limited. This tendency has led them to underperform and meant that a significant portion of their produce would be shared amongst the few traders in their remote small market. This underperformance tendency of small-scale farmers tends to affect achieving sustainable development goals. To obtain the data, the author administered a structured survey to small-scale farmers carrying out agribusiness in the sub-Saharan African countries. This survey was divided into two sections: The demographics section and eleven statements, six relating to digitalisation and five to Agribusiness transformation, to which the participants had to answer in accordance with a 5-point Likert scale. Simple random probability sampling was used to draw a valid sample of 383 from the population of small-scale farmers. PLS structural equation modelling (SEM) using SmartPLS 4 was used to analyse the data and test the hypothesis. Results revealed a significant contribution of digitalisation of agribusiness on the market transformation of small-scale farmers' products in sub-Saharan Africa, particularly in Tanzania. This market transformation resulted from the ability of digitalisation to offer a reduced role of intermediaries, provide opportunities for farmers to expand their markets, and improve the linkage between farmers and the market through customer engagement and interaction. It was further found that digitalisation transforms agribusiness by enhancing digital advertisement, communication, and promotion and allowing easy payment methods.

Keywords: Agribusiness; Digitalisation; Small-scale farmers; Digital marketing

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1. Introduction

Historically, agriculture has been recognised as essential to economic development and promoting rural development for both the developed and developing world [1,2]. Scholars and policymakers have recorded the significant contribution of agriculture in terms of aggregate growth, exports and employment in accelerating the well-being of living standards of many communities [3-5]. This has led the agricultural sector to be vital in addressing some sustainable development goals, which include hunger, poverty, inclusive and equitable quality education, gender equality, empowering all women and girls to healthy lives and promoting well-being for all at all ages. For example, Praburaj [4] found and concluded that agriculture is the primary food supply source for the world's underdeveloped, developing or even developed countries. They further advocate agriculture as one of the most effective ways the sector promotes economic growth and nation-building through its close ties to the rest of the economy. As a result, the agriculture sector is seen as the foundation of all development efforts in rich and developing nations.

Despite the potentiality of the agriculture sector, it is well acknowledged that in sub-Saharan Africa, the agriculture sector is dominated by small-scale farmers who face many constraints that hamper them from normal agriculture to commercialising their agricultural products. For example, Pandey and Pandey [6] have found that limited access to accurate and timely market information impedes farmers' marketing of farm produce in sub-Saharan Africa. They added that the limited access to market information has led to the high cost of transactions and the emergence of intermediaries. Smidt [7] has found that small-scale farmers face the challenge of accessing proper market information to channel their products to the right market, leading them to sell their farm produce at low prices through intermediaries. On the other hand, Vasumathi and Arun [8] advocated that many small-scale farmers don't have access to quick and consistent marketplaces to sell their produce. Thus, they have little need to expand into large-scale farming to increase their income. Due to this circumstance, African governments have prioritised agricultural and agribusiness transformation on their policy agenda to combat issues like food and nutrition insecurity, climate change, young unemployment, and overall economic growth. The continent's agriculture might become a powerhouse to feed a burgeoning population and build a respectable agribusiness structure that could employ millions of young people with the correct policies on innovation.

Realising the importance of agriculture and the problem faced by small-scale farmers, it is seen in the agriculture policies and empirical evidence that when agribusiness is transformed through digitalisation, it will support the growth and performance of the agribusiness sector and it will contribute to the achievement of sustainable development goals [9,10]. "Digital native" young entrepreneurs at the forefront of innovation applied to many economic sectors, according to Kaur and Sandhu [11]. They have a window of opportunity due to technology's tendency to bring nations closer together, lower trade barriers, and otherwise improve the world. Digitalisation in agriculture could be a game-changer for increasing productivity, profitability, and climate change resilience [12]. A significant agribusiness might be achieved with the aid of an inclusive, digitally enabled agricultural transformation, improving the standard of living for Africa's smallholder farmers [13]. It might increase the involvement of women and young people in agribusiness and open up job opportunities along the value chain. According to Izuogu et al. [14], the digitalisation of agribusiness has reduced the need for intermediaries, given farmers the chance to expand their markets, and strengthened the connection between extension and research centres and small-scale farmers' productivity and way of life.

Additionally, Chinakidzwa and Phiri [15] have promoted the idea that digitisation presents a chance to reduce expenses, boost visibility, enhance customer relationships, provide better market sensing, and boost customer convenience. They noted that one strategy for providing farmers with a comprehensive education platform is to digitalise the agriculture industry. According to Kaur and Sandhu [11], Farmers confront weak road networks, price volatility, and a lack of market knowledge, making digital innovation a crucial alternative to connect farmers to markets. As a result, with the rise in global population and the need for food production to achieve sustainable development, digitalisation will assist farmers in conducting agribusiness by enabling easier access to marketing.

Despite the acknowledgement of the contribution of digitalisation of agribusiness and the emergence of recent technology, which is affordable and accessible by small farmer's agribusiness. Most sub-Saharan African nations have fallen short of the standards necessary for an effective agricultural revolution, and the productivity of African agriculture is significantly lower than that of the rest of the world [16,7]. These sub-Saharan African nations' agricultural performance is still woefully inadequate and unquestionably far below their agribusiness potential [17]. Small-scale farmers continue to be underrepresented in agribusiness practices because of the intermediate [16]. Farmers are frequently ill-equipped to assess whether digital platforms and activities are appropriate [17,16]. As a result, it is currently uncertain if the digitalisation of the agriculture industry will be able to change small farmers' agribusiness in a way that will support sustainable development objectives. Given the region's booming population, extreme poverty, rapid urbanisation, and problems with food security, Sarker et al. [9] claimed that connecting smallholder farmers and markets in sub-Saharan Africa is essential to release the full potential of the agricultural sector in the area. This study aims to close this gap by examining how agribusiness digitalisation transforms the marketing and distribution of produce by small-scale African farmers in sub-Saharan African countries, specifically Tanzania.

2. Literature Review

2.1 Conceptualisation of Key Terms

Digitalisation

Varas [18] defined digitalisation as the change from a traditional business to a digital one. That is the use of digital technologies to change a business model and provide new options for earning money and creating value. Additionally, Bowen and Morris [19] described digitalisation as the process of transforming a business model using digital technologies to create new revenue streams and value-creating opportunities. According to Bajrang [20], digitalisation incorporates digital tools and systems into different corporate functions, such as management, communication, manufacturing, and customer service—Sarker et al. [9] defined digitalisation as making workflows and processes easier and more efficient.

The Agriculture Sector

According to one definition of agriculture, it is a way of life that encompasses raising animals, fish, crops, and forest resources for human use and providing the agro-allied goods our industries need [21]. Contrarily, the agriculture sector is defined by Varas [18] as the sub-sectors that include crop, livestock, and fishing. Agriculture was defined by Chung et al. [22] as a sector of the economy that encompasses the production of crops and animals as well as agricultural engineering and the creation of agricultural equipment, fertilisers, and other farming-related items.

Agribusiness

According to Davis and Goldberg [23], agribusiness is the aggregate of all activities involved in producing and distributing farm supplies, farming operations, and the storage, processing, and distribution of agricultural products and commodities. Another definition states that it consists of businesses with a profit motive that supply agricultural resources and process, market, transport, and distribute agricultural products and consumer goods [24]. Agribusiness is defined by Huang and Chen [25] as the science that coordinates the production, processing, and distribution of food and fibre as well as the provision of inputs for agricultural production.

Agribusiness Transformation

A general definition of agricultural transformation is the transition of the agrifood system from being farm- and subsistence-oriented to being more commercialised, productive, and off-farm-oriented [26]. According to Jayne et al. [5], agricultural transformation results in higher farm productivity, making farming commercially viable and bolstering interlinkages with other economic sectors.

2.2 Cognitive Response Theory

This theory was defined by Anthony Greenwald in 1968, assuming that marketing tools can influence the relative importance that individuals attach to various product attributes, purchase decisions being purely rational [27]. In this paper, digitalisation as a marketing tool can influence the relative individual or farmers attached to a local gastronomic experience. According to the cognitive response theory, people's evaluative reactions to information that is relevant to their attitudes are the main cause of attitude change. The theory links this study since it explains the ability of digitalisation, such as having a responsive influence on the transformation of agribusiness among small-scale farmers.

The applicability of cognitive response theory in studying the influence of digitalisation on the transformation of agribusiness marketing among small-scale farmers is observed in some studies [28,29]. For example, Khanna [28,30] states that the digitalisation of agriculture is enabling the collection of enormous volumes of geo-referenced data regarding growth conditions in the field and making it possible to automate the implementation of input applications with a variety of spatial constraints.

Despite the applicability of the cognitive response theory, this theory has vague operational variables relevant to the study of the influence of social media marketing on local gastronomic experience. To address this weakness, the empirical literature review was used to construct the operational variable in this study. Hence, this theory helped to link the influence of social media marketing on branding local gastronomic entrepreneurship.

2.3 Empirical Literature Review

Reddy [30] conducted a study on the impact of digitalisation on agribusiness in India. Findings indicated that digitalisation significantly influences small-scale farmers to access multiple buyers for their products and get higher prices. He further found that through digitalisation, the agents and intermediaries are not getting involved in the digital marketing system, increasing the farmers' profit. Moreover, he concluded that the digitisation of agribusiness tends to produce market updates that can reach producers and consumers in a fraction of a second [31].

In their study of the digitalisation of agriculture in Nigeria, Usman et al. [32] demonstrate how the digitalisation of agriculture has reduced the need for intermediaries, given farmers the chance to expand their markets, strengthened the connections between extension and research centres, and increased the productivity and standard of living of small-scale farmers.

On the other hand, Sharma et al. [33] carried out a study on digitalisation in the field of agricultural marketing. Findings demonstrate how digitalisation contributes to the use of electronic exchange trading of agricultural products and online placing of orders for agricultural product distribution. They further found digitalisation to promote the use of digital distribution channels which in turn help farmers avoid intermediary structures and to increase profits.

Rolandi et al. [34] carried out a meta-analysis of empirical evidence on the impact of digitalisation on agriculture and rural areas. They noted that digital technologies in agriculture helped to increase precision in the decisions on which crops to grow by market trends and distribution channels and on when to intervene with agricultural work. They added that digitalisation may reduce costs for farms and promote agricultural production.

Because the interconnectedness of digital instruments that characterise digitalisation has created a new sociotechnical context in which human activities are carried out [35,36], experts refer to digitalisation as the fourth industrial revolution Rural and agricultural areas are also affected by these phenomena [37]. While smart farming encompasses the entire value chain (before, during, and after on-farm production, including e-commerce platforms, blockchain-enabled food traceability systems, and precision agriculture itself), precision agriculture can be viewed as being related to on-farm activities involving specific digital solutions (e.g., yield mapping, GPS guidance systems, and variable rate application). Similar to digitization, digitalisation is a process that builds on digitization by adding interconnection, which broadens the range of domains involved in innovation and leads to socioeconomic and institutional changes [38].

According to Rotz et al. [39], automatized agriculture not only creates new job opportunities and greatly improves the lives of farmers and workers who can use digital technology, but it also causes a sharply split labour market, which exacerbates social inequalities.

Therefore, there are lower-skilled workers in the fields, greenhouses, and warehouses who are subjected to increased scrutiny and surveillance, further rationalisation of their workplaces, and ever-escalating expectations of productivity on the one hand, and highly-skilled trained digital workers who increase productivity and efficiency on the other. Robots and automated solutions run the risk of replacing these low-skilled labourers. Additionally, according to Jakku et al., Özen and Grima and Vedrana et al. [40-42] digital tolls cannot help achieve the SDGs for Climate and the environment.

Moreover, Vasconez et al. [43] in their study on human-robot interaction in agriculture advocated that human-robot interaction can contribute to an increase in productivity and facilitate work in agricultural activities, such as fruit harvesting, handling heavy crops and fertilizer load bags, and delivering and transporting in shared environments. They show that typically, agricultural robots are autonomous or semiautonomous devices that can be controlled at various phases of the process to address challenging issues and used for repetitive operations such as land preparation, water irrigation and spraying, trimming, harvesting, monitoring and inspection, and mapping in an effort to lessen the farmer's workload and optimise process times and costs.

Ravi et al. [44] found and concluded that digital marketing tools are one of the best ways to connect with customers and attract them. They further added that digital marketing technologies and tools can be used more effectively for the improvement of the traditional marketing strategy.

Alekhina et al. [33] discussed the current state and future potential of digital technologies in agricultural marketing, particularly e-channels for the promotion of agricultural products. They note that the main digital promotion methods included an electronic system for placing state orders that took into account the benefits and drawbacks of trading on electronic platforms, submitting proposals for the purchase of agricultural products from online retailers, and maintaining one's own website.

Accelerating the formation of digital systems is a key factor in the current era's high-quality agricultural improvements. Digitalisation is one of the most important aspects of agricultural progress. The magnitude of e-commerce transactions and the entire amount of the telecommunications industry are the two biggest roadblocks to agricultural digitalisation, from the standpoint of challenges. It is necessary to capitalise on the advantages of high-value areas, strengthen the coordination system among various departments, and expedite the building of rural infrastructure in low-value areas in order to speed the development of the entire agricultural industry chain. Additionally, in order to foster various regional development models that are compatible with local circumstances, interregional communication and cooperation must be improved through digitalisation [45,46].

According to Kondratieva [47], the goal of regulating digital transformation in agriculture is to make it easier to monitor business operations' adherence to the standards of inclusivity and climate neutrality rather than to boost their economic effectiveness. The Common Agricultural Policy's (CAP) digitization plan moves the program's objectives closer to those of sustainable development. Accordingly, the goal of regulating digital transformation in agriculture is to make it easier to monitor business operations' adherence to the standards of inclusivity and climate neutrality rather than to boost their economic effectiveness. The objectives of the Common Agricultural Policy (CAP) come closer thanks to the digitalisation plan.

2.4 Conceptual Framework

Based on the theory of digitalisation facilitation and digitalisation transformation process, as noted in the literature above, we have drawn up the following conceptual framework in which we will frame our study (Figure 1).

3. Methodology

3.1 Research Paradigm

The positivism paradigm was used, asserting that actual events can be observed theoretically and empirically and explained using statistical methods [48]. The current study used many theories and previous empirical studies from different contexts to analyse digitalisation's influence on agribusiness's transformation among small farmers' marketing perspective. Through this available empirical evidence and theories, the researcher was able to construct a hypothesis on the significant relationship between digitalisation and agribusiness transformation among small farmers' marketing perspective. Further, this study was set to positivism, using statistical methods and building on evidence from available theories and empirical studies. Hence in this study positivism paradigm served the purpose.

3.2 Research Approach

A quantitative approach was used to determine small farmers' marketing perspective on the influence of digitalisation on agribusiness transformation. As Creswell [49] argued, the quantitative research approach is designed to test the hypothesis and assess its significant relationship in a quantifiable form. Hence, due to the need to test the hypothesis on the influence of digitalisation on the transformation of agribusiness, the quantitative approach was suitable in all steps of this study.

3.3 Research Design

The cross-section research design was used in the current study to establish the data collection and analysis process. As argued by Saunders and Thornhill [48], the cross-sectional design is a design that enables a researcher to collect data from many subjects at a single point in time. They further argued that the premises of cross-section lie in the fact that the reality and knowledge gaining are evidenced when one collects data at one time. Even in the current study, a cross-section research design helped the researcher collect data on the significant influence of digitalisation on the transformation of agribusiness among small-scale farmers. Hence, in this study, a cross-section research design helped the researcher establish reality and knowledge evidence by collecting data at one point to understand how digitalisation transforms agribusiness among small farmers' marketing perspective.

Independent Variables		**Dependent Variables**
Digitalisation		**Agribusiness Transformation**
D1: Digital Advertisement	⟶	AT1: Cost optimization
D3: Digital Communication		AT2: Offset middlemen
D4: Digital Promotion		AT3: Market Information
D5: Digital Payment		AT4: Customer engagement and Interaction
D6: Digital Money		AT5: Real time market update

Figure 1. Conceptual framework.

Source: Authors' compilation.

2.4 Study Area

This study collected data in sub-Saharan Africa especially Tanzania. Tanzania was selected because it comprises various agribusiness sectors from which many small-scale farmers motivated to raise their agribusiness market performance are served. This study's target respondents are small-scale farmers working in agribusiness or selling their products to agribusiness.

There are several digitalisation services for farmers despite farmers not being very active with digital tools. Therefore, it helped to build evidence based on small-scale farmers who own agribusinesses. On the other hand, Southern Highland has many economic activities that small-scale farmers conduct. Hence, the southern highland zone is a potential area that qualifies for collecting data for the current study to understand the significant influence of digitalisation on the transformation of agribusiness among small farmers' marketing perspective.

Small-scale farmers, often known as smallholder farmers, are people or households who carry out agricultural pursuits on a modestly sized plot of land. Small-scale farming can be defined differently depending on the situation, the nation, and the particular standards applied, such as the size of the farm, the scale of the production, or the degree of revenue [50].

3.5 Population and Sampling Design

Study Population

According to Creswell [49], a population is any collection of individuals or things that are the focus of a certain survey and are related in some way. As noted above, the study population was small-scale farmers carrying out agribusiness in the southern highland zone. This particular group of people was chosen specifically because small-scale farmers strongly influence the final decision regarding the digitalisation of their agribusiness services in agriculture. Thus, the current study's data were collected from a qualified population of small-scale farmers to assess the significant influence of digitalisation on the transformation of agribusiness among small-scale farmers from a marketing perspective.

Sample Size

An alternative to Cochran's formula for determining sample size from a population is explained by Yamane [51]. He asserts that the sample size for a 95% confidence level and a p-value of 0.05 should be:

$$n = \frac{N}{1 + N(e^2)}$$

N is the population size, n is the sample size, and e is the degree of precision. When our population is calculated using this formula, population (N) = 1120 with a precision(e) of 5%. Using p = 0.5 and a 95% confidence interval, the sample size is as follows:

$$n = 1120/(1 + 1120(0.05^2))$$

$$n = 1120/2.6175$$

$$n = 400$$

Hence, to generalise our findings for the whole population at 95% confidence, we needed to collect a sample size (n) of 400 respondents for this study. However, we collected 383 valid responses, deemed adequate for producing valid and reliable research results with a +/– 9.17% error. Also, using the minimum sample size suggested by Hair Jr. [52], which would be 10 times the independent variables, would mean that we would only require a sample of 60. We then used PLS-SEM to analyse the data. Performance estimators of PLS-SEM are not affected by a small or large sample in producing long-lasting results, but rather PLS SEM tends to enhance sampling distribution to approach normality.

Sampling Technique and Procedure

Simple random sampling was used to pick our sample; the suitability of this technique is due to its ability to ensure an equal chance for each element of the population to be included in the study. In the current study, each small-scale farmer involved in agribusiness had an equal chance of being selected and included in the study process. This is because all small-scale farmers in agribusiness are homogenous, and they have the same information on the significant influence of digitalisation on the transformation of agribusiness among small-scale farmers. Hence, simple random sampling was considered suitable for choosing samples during data collection.

3.6 Data Collection Tools

A structured questionnaire and document review were used for our data collection. This structured questionnaire was taken from prior empirical studies to capture measurable data for statistical hypothesis analysis. The questionnaire comprised two sections. Section A composed of general data with three questions relating to gender, Age and experience and section B comprises eleven questions divided into two themes, one being digitalisation and the second being Agribusiness transformation. Participants were asked to respond using a Likert scale with a maximum score of 5. "1" stands for strongly disagreeing, "5" for strongly agreeing, and "3" for uncertain. According to Taherdoost [53], questionnaires are valuable for quantitative studies since they allow researchers to gather highly organised data for statistical analysis and hypothesis testing (see Appendix).

Techniques for document evaluation were also applied to bolster and support the study's data collection. According to Creswell [49], the document review method supports the opinions or claims made in academic writing and may also highlight some difficulties that have gone unnoticed by other methods.

The current study used the documentary review technique of data collecting to provide additional support for the questionnaire results and a more significant interpretation of the data gathered. Studies that are now available frequently differ in terms of study design, operational quality, and study subjects. How they approach the research question could vary, increasing the evidence's complexity.

3.7 Data Analysis

As noted above, following the data collection, the data analysis was performed using Partial Least Square Structural Equation Modeling (PLS-SEM) with SmartPLS 4. According to Hair et al. [52], the reason the researcher chose PLS-SEM is that the analysis relates to testing the theoretical framework of predictive perspective and when the structural model comprises many observed variables and latent variables from which the research is required to perform exploration of factor structure before actual testing of the hypothesis. In the current study, the hypotheses are designed using latent variables such as agribusiness transformation as the dependent variable and digitalisation as an independent variable and their respective observed variables. Having the nature of these two kinds of variables, observed and unobserved variables, in the conceptual framework of the current study, PLS-SEM was a suitable method for analysing this kind of model.

When the model consists of numerous constructs and elements, PLS-SEM delivers solutions with modest sample sizes, according to Hair et al. [54]. When distributional difficulties, such as a lack of normality, are a concern and the study calls for scores of latent variables for follow-up analysis, PLS-SEM also performs very well with high sample sizes. Technically, this is made possible by the PLS-SEM algorithm, which computes measurements and structural model links separately rather than all at once. Regardless of whether the data comes from a generalised or mixed population, Hair et al. [52,55] highlight how PLS-SEM offers a solution when techniques like CB-SEM produce unacceptable or inconsistent findings with complex and small models and sample sizes. On the other hand, exploration research that looks at undeveloped or still-developing hypotheses can benefit from PLS-SEM's higher statistical power qualities.

According to these authors, PLS should be viewed as a more open-ended version of SEM that supports composite and common factor models. This method examines the structural link between measured variables and latent constructs by combining component and multiple regression analyses. On the other hand, PLS-SEM enhances sampling distribution to approach normality; it allows models to use fewer indicators (1 or 2), but it can also handle a model with more indicators up to 50+ [55]. Scholars argue that PLS-SEM is suitable for theory development and prediction [53].

On the other hand, Fauzi [56] argued that SEM allows considering divergent and convergent validity in all variables to show model fit and allows specification searches to find better fitting models to the sample variance matrix. PLS-SEM allows the use of several indicator variables per construct simultaneously, which leads to more valid conclusions at the construct level [54]. Hence based on this, PLS, SEM is considered essential.

Additionally, PLS-SEM enables simultaneous assessments of all interactions between constructs and a set of relationships between one or more independent variables and one or more dependent variables [56]. To identify the significant relationship in this study, the three hypotheses from the conceptual framework will be simultaneously evaluated. In contrast to conventional regression analysis, this is possible because PLS-SEM considers many equations at once. This implies that a variable may act as both a predictor (regressor) and a criterion in different equations. PLS-SEM is frequently utilised because it allows for the simultaneous measurement of multiple variables and their interactions. Because it enables the simultaneous examination of relationships between variables, it has a broader range of applications than other multivariate techniques. Although PLS-SEM is appropriate for this investigation, it is frequently regarded as being complex and challenging to comprehend.

A systematic literature review tries to locate, evaluate, and synthesise all empirical data that satisfies pre-established eligibility requirements to address a research topic. According to Byrne [57], a systematic review is a statistical evaluation of the information presented by several research or sources that try to pose or respond to the same question. On the other hand, a systematic review is defined as one that is conducted to summarise the available data on a set of topics with a thorough research strategy. The current study will use the systematic review method to assess secondary data obtained through document review.

3.8 Validity and Reliability

Validity

According to Rusticus [58], validity assesses whether the research instrument truly measures what it was intended to measure and content validity ensures that all contents are captured in the course with greater emphasis on more in-depth context. According to Yusoff [59], face validity concerns whether a measure seems relevant. We ensured content validity, construct validity and predictive validity by first carrying out a pilot study to gain expert opinion to evaluate if the indicator or operational variables were relevant and appropriate to the construct designed and asked respondents to review the instrument to determine whether they measured the concept intended measure.

Convergent validity is the extent to which the construct converges to explain the variance of the items. The average extracted variance (AVE) for all items in each construct was used as a metric for evaluation. An acceptable AVE is 0.50 or higher, indicating that the construct explains at least 50 percent of the variance of the items [53]. Then we assessed discriminant validity, namely the extent to which the construction is empirically different from other constructs in the structural model. In such a setting, an HTMT value above 0.90 would indicate that discriminant validity does not exist [52].

Reliability

Haji-Othman and Yusuff [60] advocate that Reliability is the degree to which research results are consistent over time and accurately represent the total population under study. The current study ensured Reliability by conducting a pilot study before a main survey to soften the language of the instrument and remove the ambiguity of the data collection tools. Removing ambiguity helped clarify the questionnaire, improving the level of repeatability. Further, although the language of reporting this Research is English, to ensure repeatability, we used the Swahili version to ensure a clear understanding of the questionnaire by respondents who are native Swahili speakers. We tested the internal consistency of the collected data using Cronbach's alpha statistic. However, Cronbach's alpha assumes that all items are equally reliable and have equal outer loadings on the construct [61,62]. Because of the limitation of Cronbach's alpha, this study also used composite Reliability to measure internal consistency. Composite Reliability considers the different outer loadings of the items in the construct. According to Hair et al. [61], it is acceptable if Cronbach's alpha and composite reliability values score between 0.70 and 0.90. Cronbach's alpha value and composite reliability values of less than 0.70 show a lack of internal consistency reliability.

4. Findings

4.1 Respondents Profile

In this study, it was necessary to profile respondents' gender, Age and agribusiness experience because they moderate the effect of digitalisation in any social science activities [62]. Including these variables in the information system studies could help provide a real picture of the community concerning the utilisation of digital tools. Hence, these variables are very important to be included in any social research as each variable moderates different respondents' behaviour concerning the digitalisation of agribusiness, and they are used to provide a picture of the respondents involved in the study (Table 1).

Table 1. Respondents profile.

Variable	Measurement	Frequency	Percent
Gender	Male	214	55.9
	Female	169	44.1
Age	18-27 Years	135	35.5
	28-37 Years	79	20.6
	38-47 Years	60	15.7
	48-57 Years	58	15.1
	58-67 Years	31	8.1
	Above 67 Years	20	5.2
Experience in Agribusiness	Less than 5 Years	131	34.2
	Five to 10 Years	199	52
	Above 10 Years	53	13.8
Total		383	100

Source: Field data.

4.2 Validity and Reliability

The quality of any research is established by ensuring validity and reliability issues are cared for in the research process. This study used SmartPLS 4 SEM; therefore, the findings for validity were provided during the reflective measurement and structural model formulation, as presented below.

Evaluation of Reflective Measurement Model

To ensure the validity of the findings, a reflective measurement model was run and assessed to check the output's construct validity and criterion validity. The model was evaluated using the following metrics: indicators loadings, internal consistency, convergent validity, and discriminant validity to check if they align with the recommended value established by previous scholars. The reflective measurement model was run for the first time to determine the validity of the construct, namely digitalisation and agribusiness transformation, as stipulated in Figure 2 below. The model did not perform at a first run, due to the fact that the following indicator variables D2—"Digital Invoicing" and D6—"Mobile Money"; AT1—"Optimise Operation Cost" and AT5—"Real-Time Market Updates" had a low loading of less than 0.7. It is argued that if the indicator scores a loading of less than 0.7 it affects the model performance due to the fact that it will affect the value of AVE, HTMT and composite reliability. We therefore removed these indicator variables due to the fact that they had low loading of less than 0.7 which affected negatively the value of the AVE, HTMT and composite reliability. Figure 2 presents the indicator variables and their loading which relate to the recommended loadings by Hair et al. [63].

Using SmartPLS we produced Figure 2, and produced the output is listed in Tables 3 and 4 to check for model validity. Table 2 shows the measurement model construct.

Indicator Loading

A valid reflective measurement model must produce a loading of 0.7 and above for all indicator variables [52]. In Figure 2 and Table 3, all indicator variables have scored a loading of > 0.7, aligned with the recommended value suggested by prior scholars.

Reliability and Convergent Validity

The reliability is assessed using Cronbach's alpha and composite reliability, where scholars have recommended that a reliable model should produce both Cronbach's and composite reliability, i.e. a p-value > 0.7 [64]. In Table 4, all constructs have scored a p-value > 0.7 for both Cronbach's and composite reliability which is aligned with the recommendation made by prior scholars for the model to be reliable. On the other hand, convergence validity was assessed using average variance extracted (AVE), which is recommended to be 0.5 and above for a model to meet convergence validity [65-68]. In Table 4, the results for AVE indicate that all constructs have scored the value of AVE > 0.5, which is recommended and accepted by prior scholars for the model to achieve convergence validity.

Discriminant Validity

The discriminant validity must be established to confirm that the measurement of a construct (variable) is distinct from other Constructs. Two ways to check discriminant validity exist 1) The Fornell-Larcker Criterion and 2) the heterotrait-monotrait ratio of correlations (HTMT). The classical approach proposed by Fornell and Larcker [69] suggested that the square root of AVE in each latent variable can establish discriminant validity if its value is larger than other correlation values among the latent variables. To do this Table 5 created in which the square root of the AVE is calculated using SmartPLS 4 software and writ-

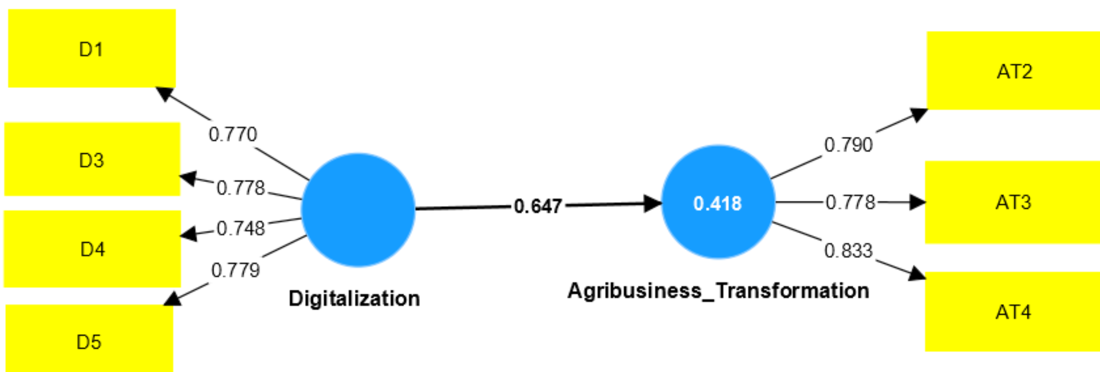

Figure 2. Reflective measurement model.

Table 2. Measurement model constructs.

S/N	Constructs	Indicator variables
1	Digitalisation	D1: Digital advertisement, D3: Digital communication, D4: Digital promotion and D5: Digital payment
2	Agribusiness Transformation	AT2: Offset middlemen, AT3: Market information, AT4: Customer engagement and interaction

Table 3. Outer loading.

Indicator variables/ constructs	Agribusiness transformation	Digitalisation
AT2	0.790	
AT3	0.778	
AT4	0.833	
D1		0.770
D3		0.778
D4		0.748
D5		0.779

Table 4. Reliability and convergent validity.

	Cronbach's alpha	Composite reliability (rhoA)	Composite reliability (rhoC)	The average variance extracted (AVE)
Agribusiness transformation	0.720	0.725	0.842	0.641
Digitalisation	0.773	0.782	0.852	0.591

ten in bold on the Table's diagonal. The results in Table 5 suggest that the square root of AVE in each latent variable value is larger than other correlation values among the latent variables. Hence for the Fornell-Larcker Criterion, this study has achieved the recommended value for discriminant validity [69-71].

Table 5. Fornell-Larcker criterion.

	Agribusiness transformation	Digitalisation
Agribusiness transformation	**0.801**	
Digitalisation	0.647	**0.769**

For discriminant validity to be achieved, scholars have suggested that the measurement model should produce an HTMT value of less than 0.8 [52]. Since the maximum value produced in this study is 0.839 below the 0.85 thresholds (i.e., the most conservative HTMT value), discriminant validity is established in the model (Table 6).

Table 6. Heterotrait-monotrait ratio HTMT list.

	Heterotrait-monotrait ratio (HTMT)
Digitalisation > Agribusiness transformation	0.839

Evaluation of Structural Model

The evaluation of the structural model is based on four criteria namely collinearity assessment, path coefficient assessment, model explanatory power and predictive power. In this assessment, we used; the variance inflexion factor (VIF), the p-value, the R square and the F square (F-Size).

Collinearity Assessment

Multicollinearity is used to check if each set of exogenous latent variables in the model in Figure 2 is checked for potential collinearity problems to see if any variables should be eliminated, merged into one, or have a higher-order latent variable developed. For a model construct to suffer from a collinearity problem, it should produce a variance inflexion factor above 5 [72,73]. Table 7 of this study indicates that no constructs suffered from the collinearity problem since their VIFs were lower than five, as shown in Table 7.

Table 7. Collinearity statistics (VIF).

Indicator Variables of the Constructs	VIF
AT2	1.432
AT3	1.349
AT4	1.481
D1	1.621
D3	1.483
D4	1.675
D5	1.400

Path Analysis and Hypothesis Testing

The study was designed to test digitalisation's significant influence on agribusiness transformation among small-scale farmers. This is a very important stage in assessing the hypothetical relationship between the predictor variable (Digitalisation) on the outcome variable (agribusiness transformation). The structural model was run to assess the study's hypothesis, and the results from the structural model are presented in Figure 3. In Figure 3 path coefficient of both the hypothetical relationship of the independent variable to the dependent variable indicates a significant relationship using the p-value of less than 0.05. Furthermore, Figure 3 shows the significant influence of each indicator variable since all indicator variables have scored a p-value of less than 0.05. Hair et al. [52] recommended a p-value of 0.5 or less for a model hypothesis to be significant. Hence in the current study, all indicator variables were contributing to explaining the significant influence of independent variables to the dependent variables.

Further analysis of the path coefficient is presented in Table 8 using t-statistics and p-value.

Table 8 illustrates the path coefficient of the predictors' variable (Digitalisation) towards the outcome variable (Agribusiness Transformation). This is predicted well using the p-value at less than or equal to 0.05. Hence in this study, the significant influence of digitalisation on agribusiness transformation is significantly important.

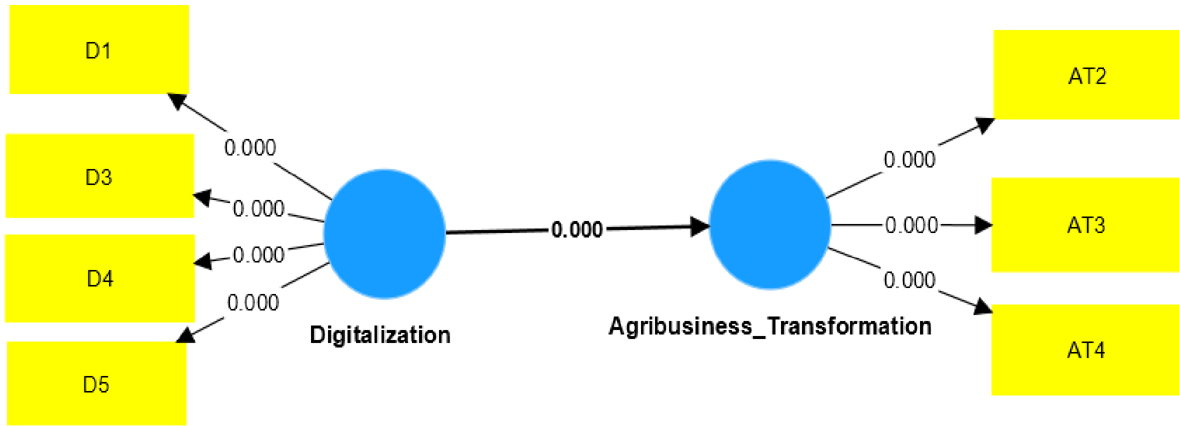

Figure 3. Structural model.

Note: D1: Digital advertisement, D3: Digital communication, D4: Digital promotion and D5: Digital payment contribute to the transformation of agribusiness through AT2: Offset middlemen, AT3: Market Information, AT4: Customer engagement and interaction.

Table 8. Path analysis.

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Digitalisation > Agribusiness transformation	0.647	0.649	0.038	17.176	0.000

Model Explanatory Power and Predictive Power

This part involves examining the coefficient of determination (R^2). The R^2 Represents the variance explained in each independent variable and is a measure of the model's explanatory power also referred to as in-sample predictive power. R^2 ranges from 0 to 1, with the higher value indicating a greater explanatory power.

Table 9 indicates the R^2 of the model of 0.417. Falk and Miller [72] recommended that R^2 values should be equal to or greater than 0.10 in order for the variance explained by a particular endogenous construct to be deemed adequate. This means that the variance explained by the independent variable namely digitalisation (R^2 = 0.417) the model predictive power is satisfactory.

Table 9. Model explanatory and predictive power.

	R-square	R-square adjusted
Agribusiness transformation	0.418	0.417

5. Discussion of the Findings

This study hypothesised the relationship between digitalisation and agribusiness transformation of the marketing operation of small-scale farmers. The finding of this study has revealed a significant influence of the digitalisation of agribusiness on the transformation of marketing operations among Small-scale Farmer holders. The agribusiness sector has enhanced the transfer of information and ideas related to market information. This collaborates with the argument made by Balkrishna and Deshmukh [70] on market information in Nigeria. The study supports the cognitive response theory, as described by Ehlers et al. [27] that argues the importance of digital marketing tools in influencing individuals' relative importance to various product attributes with purely rational purchase decisions**.** This implies that when farmers adopt digital technologies, it will transform their agribusiness through access to useful market information and will bridge the current knowledge gaps. The current study supports the findings from prior studies by Reddy, Inegbedion et al., and Rameshkumar [30,71,73] that digitalisation of the agriculture sector significantly influences agribusiness transformation among small-scale farmers. This implies that findings from one context on the digitalisation of agribusiness can be transferred to other contexts to evidence the importance of digitalisation in agribusiness.

While the current study corroborates with some prior study's findings on the significant influence of digitalisation on agribusiness's transformation, they differ in terms of explanation of why digitalisation transforms agribusiness. Notably, Reddy [30] has explained that digitalisation has a significant influence on the transformation of agribusiness due to its ability to increase the selling price and reduce market cost through the enhancement of digital customer engagement and high conversion rates to buy agricultural products. On the other hand, Rameshkumar [73] found that digitalisation tends to transform the agribusiness sector by its power to create digital distribution channels that address the problem of intermediary structures in the Russian farmer's marketing sector. He added that digitalisation is helpful to farmers to reach out to multiple buyers, obtain higher prices for their products, and ensure profit maximisation. The current study found that the possible explanation of why digitalisation transforms agribusiness is that the digital structure tends to bypass the intermediary structure, which is an advantage for small-scale farmers' profit. It is further explained that digitalisation tends to transform small-scale farmers' communication structure and advertisement to be more effective and real-time efficient. The difference observed in explaining the significant influence of digitalisation is the many attributes and the contextual differences. This implies and promises that using digital tools in agribusiness improves the ability of small-scale farmers to benefit from sales outlets for their farm produce [74].

From a different perspective, some prior studies did not support the current study findings on digitalisation's influence on agribusiness transformation. Notably, Atovich et al. [75] found the insignificant influence of digitalisation on agribusiness transformation. They argued that the insignificant influence was observed due to the complication of integrating information resources into small-scale farmers' operations and the lack of compatible software and Internet technologies to fit small-scale farmers' business environments. Similarly, Chille [76] noted that the insignificant influence of digitalisation on agribusiness was due to the application of technology to small-scale farmers, which was incompatible with their capital. This concurs with those who argue that small-scale farmers are simple to establish and need simple and affordable technology to align with their capital [77]. This implies that when establishing digitalisation for small-scale farmers, one should select the technology compatible with small-scale farmers' operations. On the other hand, Abdulqader et al., Sharma et al., and Sood et al. [78-80] found that digitalisation's insignificant contribution to agribusiness transformation is influenced by the level of illiteracy among small-scale farmers, which resulted in their inability to perceive the benefit of using digital services in their marketing operation. This is contrary to the findings of our current study in which the digitalisation of agriculture was based on the use of simple technology such as mobile phone and application which was affordable and simple to apply and operate by small-scale farmers.

6. Conclusions

This study concludes that the digitalisation of the agriculture sector significantly impacts agribusiness transformation. It further concludes that the effect of digitalisation in this study is accounted by the ability of digital services to address the intermediaries' problems, enhance communication and the efficiency of advertisement of small-scale farmers' operations which create customer information, engagement and interaction. The study also concludes that the impact of digitalisation on small-scale farmers is observed when farmers use affordable and simple digital technology, which is clear and understandable by small-scale farmers.

Small-scale farmers can adopt digital technology when it is compatible with their nature, and once adopted and understood, it can transform their business market operation. Although African farmers are observed to be slow in adopting digital technology, the study's findings imply that they can quickly adopt digital technology that is compatible with their nature. Small-scale farmers cannot afford high-end technology. Moreover, although literature tends to highlight that small-scale farmers do not have the technical know-how of digital technology, from the discussion of the findings, we note that small-scale farmers adopt digital technology when it is simple, such as mobile phone technology which is also easy to use.

The study assumes the same level of education for all respondents. Although this might not be the case, it could be a case for further research. Also, this study collected data in sub-Saharan Africa, specifically Tanzania. This Tanzania zone was selected because it comprises various agribusiness sectors from which many small-scale farmers motivated to raise their agribusiness market performance are served. Although this does not necessarily reflect the position of the whole small-scale agribusiness sector, which may differ due to cultural, political and communication differences, we have tried our best to link to studies carried out in countries outside sub-Saharan Africa. Also, one can use this study as a benchmark for other research on small-scale agribusinesses in other regions.

Author Contributions

All authors contributed equally to this article.

Data Availability

The data presented in this study are available on request from the corresponding author.

Conflict of Interest

All authors disclosed no conflict of interest.

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Appendix

Survey

Section A: Demographics

Please choose the appropriate answer by putting a tick in the space provided.

1) What is your gender? ☐ Male ☐ Female	2) Which of the following categories describes your Age? ☐ 18-27 years ☐ 28-37 years ☐ 38-47 years ☐ 48-57 years ☐ 58-67 ☐ Above 67 years
3)What is your experience in Agribusiness ☐ Less than 5 years ☐ Five to 10 Years ☐ Above ten Years	

Section B: Digitalisation of agribusiness

For the following statements, please indicate your level of agreement or disagreement on the following statements based on the following scale;

5 = Strongly agree, 4 = Agree, 3 = Not sure, 2 = Disagree and 1 = Strongly disagree

Digitalisation					
D1:In our business, digitalisation enables online advertisement	1	2	3	4	5
D2:We offer digital invoicing through the digitalisation of our agribusiness market system	1	2	3	4	5
D3: Digitalisation has enhanced our business communication system	1	2	3	4	5
D4: It is easy to promote our business through digital tools	1	2	3	4	5
D5:Payment has been made possible through digitalisation	1	2	3	4	5
D6: Mobile money services are always available and easily accessed in our business.	1	2	3	4	5
Agribusiness Transformation					
AT1: Digitalisation has enabled our business to optimise operation cost	1	2	3	4	5
AT2: The adoption of digital services has addressed the problem of working with the middlemen	1	2	3	4	5
AT3: Much information is available in the digital services	1	2	3	4	5
AT4: Customer engagement and interaction have been easy due to the digitalisation	1	2	3	4	5
AT5:We are getting real-time market updates through digital services	1	2	3	4	5

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RESEARCH ARTICLE

Resources Integration Theory and Gray Correlation Analysis: A Study for Evaluating China's Agri-food Systems Supply Capacity

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Abstract: China's agri-food systems face the challenge of ensuring food and grain security for a large population with limited resources. This paper constructs a resources integration theory, which classifies agricultural resources into six types and measures their correlation with food and grain supply capacity using grey correlation analysis. The results show that, during 2002-2020, among the factor resources, the highest correlation with food and grain was technology; among the related industry resources, the highest correlation with food was rural roads, and with grain was agricultural machinery; among the demand resources, the highest correlation was domestic market; among the six types of resources, the highest correlation was government resources; and the static correlation evaluation indices of agricultural resources with food and grain supply capacity were 0.8312 and 0.8090, respectively, indicating a compare match. Based on the results, this paper argues that the Chinese agri-food system is matched with agricultural resources, but still needs to be improved to achieve a high match. Opportunity resources, foreign investment, and international markets are disadvantageous resources because China has insufficient ability to stably utilize foreign resources. China's proposal of a "big food view" is conducive to reducing dependence on factor resources, especially cultivated land and water resources.

Keywords: Agri-food systems; Supply capacity; Resources integration; Gray correlation; Matching degree

1. Introduction

The Chinese government proposes to establish the big food view, develop facility agriculture, and construct a diversified food supply system. The big food view is a concept of "seeking calories and protein from farmland, grassland, forests, oceans, plants, animals, and

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microorganisms to develop food resources in all directions" [1]. The diversified food supply system is closely related to the agri-food systems, and facility agriculture is used to improve the output efficiency of the agri-food systems. China is a large country with a population of 1.4 billion, with scarce arable land and water resources, and is currently at the tipping point of moving from the middle-income to the high-income status. With the increase in economic income, people's consumption level of starchy staple foods gradually declines, while consumption of nutrient-rich meat, vegetables, fruits, and other foods increases significantly. Food diversity also makes it easier to solve micro-nutrient deficiency problems (hidden hunger). The grain view with grain security as the core expands to the big food view with food security as the focus.

China's grain view requires that agri-food systems provide sufficient cereal production to meet people's subsistence needs in terms of quantity. China's big food view requires that the agri-food system provide sufficient food variety and quantity to meet people's health and nutritional needs. The agri-food system comprises all activities and factors in the agricultural and food value chains, including their interrelationships [2]. The agri-food system is closely linked to other economic and political sectors and is a complex system of international and domestic resource integration, critical to the country's social security system and playing an important role in social and economic development. Food security is the ultimate goal of grain safety issues.

For the research on the supply capacity of the agri-food system, the relevant literature is divided into two categories. The first category is to establish a food resource potential model from the part of material resources to simulate and predict food production capacity. Tao et al. [3] employed the GLO-PEM2 model and the CASA model to estimate the primary productivity (GPP) and net primary productivity (NPP) of Chinese ecosystems using vegetation, temperature, precipitation, soil, and other factors. Fang [4] used the structural dynamics method to study the effects of natural and man-made factors such as NPP, precipitation, heated greenhouse area, road density, and snowstorms on food supply capacity (FSC). Colasanti and Hamm [5] studied the development of urban agriculture with vacant urban plots. Dai et al. [6] analyzed the food supply in the agro-pastoral zone in northern China based on land use/cover, meteorology, soil type, and Normalized Vegetation Index (NDVI). Wang et al. [7] started from the actual food production capacity of China's various types of ecosystems (farmland, grassland, waters), combined with the food part of import and export products, to examine China's actual food supply capacity.

The second category is to analyze the supply capacity of the resource-bearing population from the quantity that needs to be supplied, using either the actual food production of different kinds of food or different per capita food consumption standards. Feng et al. [8] built a land resource carrying index (LCCI) model to analyze the carrying capacity of land resources based on the relationship between food and people. Yin and Fang [9] constructed food security pressure indicators from the perspective of food acquisition capacity and food security threshold, and identified China's food security vulnerable areas. Ji et al. [10] used the regional cultivated land food production security capacity and its risk evaluation method to derive the pressure on cultivated land resources. Wang et al. [11] argued that simply using "grain" as an evaluation index of land resource carrying capacity could only reflect part of the carrying capacity, and that evaluating from the perspective of food (dietary nutrition) was more in line with the actual land resource carrying capacity. Some scholars have also extended resource carrying from natural resources to socioeconomic environment, studying the one-way impact of food consumption on the environment, society, and economy [12], evaluating whether this impact is sustainable and how to reduce it [13], such as Food System Sustainability Assessment (FSSA) [14,15], food printing [16], etc.

The resources in the first category of literature research mainly focus on natural resources and man-made resources (such as agricultural facilities, etc.). Although the second category of literature involves socioeconomic resources, it does not relate to food or grain production. As we all know, the resources required for food or grain production not only include natural resources, but are also closely related to resources such as agricultural organization, capital input, and agricultural product market needs. Therefore, there is a need to expand from natural resources to economic and social resources. In addition, both categories of literature study unidirectional impacts: The first is the impact of resources on food output, and the second is the pressure of food needs on resources. In fact, food and resources have a two-way relationship. The amount of resources determines the amount of food obtained, and food needs determine how to use resources. It is necessary to combine the two and study the supply capacity of the agri-food system from the perspective of the matching of two-way effects, in order to obtain the changes in the role of various resources in the supply capacity and find the path to improve the supply capacity of the agri-food system from the perspective of overall resources. This paper attempts to make a breakthrough in two aspects of the above shortcomings. First, it proposes the theory of resource integration to integrate natural resources and economic and social resources, and second, it studies the supply capacity of the agri-food system and the integration of resources from the perspective of the "big food view" and the "grain view" by using the grey correlation analysis that is suitable for the interaction between the two.

The supply capacity of the agricultural food system can be measured by two indicators: per capita food and per capita grain. These indicators reflect the perspectives of the "big food view" and the "grain concept", respectively. The term "grain" mainly refers to cereal crops, which have similar basic functions for human beings and do not differ significantly in their nutritional value. Therefore, the total output of all cereal crops is considered as the amount of grain. Per capita grain is also a crucial indicator of grain security. Based on the relevant research of the Food and Agriculture Organization of the United Nations, Chinese scholars suggest that the minimum grain security threshold is 400 kilograms of food per capita per year [17]. Food, on the other hand, comprises a wide range of products that provide human beings with the necessary nutrients for survival, such as meat, eggs, milk, aquatic products, sugar, oil, fungi, and beverages. Different types of food offer different nutrients and have different effects on people, making it difficult to unify them into specific physical units. The value of food reflects its utility to humans; thus, the sum of the values (constant prices) of various foods is used to represent the amount of food.

2. Research Method and Data Source

2.1 Research Method

Resource Integration Theory Analysis Framework

Porter's theory of national competitive advantage is essentially an analysis of how a given industry can gain an advantageous position in international competition from the country's perspective, and is therefore also known as the theory of industrial competitive advantage. The improvement of the supply capacity of the agri-food system can be considered as the improvement of agricultural competitiveness, which is theoretically based on Porter's theory of industrial competitive advantage. The theory comprises six elements: factor conditions, demand conditions, supporting and related industries, organization structure, strategy and competition, as well as opportunities and government [18]. These six factors are also the six resources that need to be integrated to achieve the industry's competitive advantage. Resource integration implies the stable, long-term, and relatively fixed fusion of various resources into a resource system, where different resources complement each other to form the overall optimization of the resource system. Hence, Porter's theory can be expressed as resource integration and utilization. The industry's competitive advantage position is achievable through high-quality factor resources, organization resources, related industry resources, demand resources, government resources, and good opportunities. The allocation of resources must balance the strengths and weaknesses of each resource therein. Thus, the competitive advantage theory focuses on resource integration, both domestic and foreign, which extends to global resource integration and utilization. An industry that excels in global, high quality resource integration is evidently stronger than an industry that merely possesses an advantage in domestic resource integration. Therefore, the industrial competitive advantage theory can be transformed into the resource integration theory. Factor resources are the production factors that an industry possesses, encompassing material, human, technological, capital, and infrastructure resources, etc. Demand resources refer to the size and traits of the market. Related and supporting industries mainly concern upstream and downstream industries in this industry and related industries with common technology. Organization resources refer to the fundamental status of economic organizations within the industry, organization and management forms, and performance in market competition. These four resource types are the determinants of an industry's resource integration capabilities. In addition to these four resource types, opportunities and government are two crucial resources with significant impacts on resource integration capabilities. While opportunity resources unilaterally impact the industry, the other five types of resources influence one another and form a "diamond model", illustrated in Figure 1.

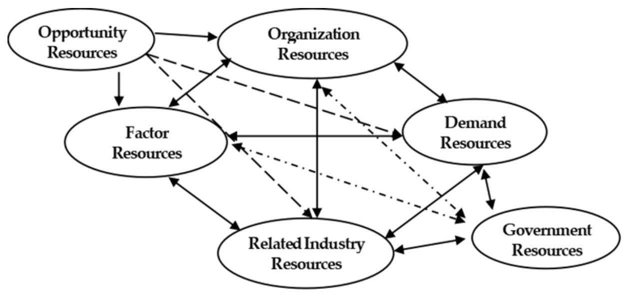

Figure 1. A theoretical framework for resources integration.

The competitiveness of the agri-food systems is evaluated through its capacity to supply, which depends on the mobilization of agricultural resources. The integration of agricultural resources is to optimize the allocation of six types of resources: balance the basic resources; use the development advantages of superior resources; make up for inferior resources; advance or retreat; take or give up on the basis of maintaining basic balance. During the integration of resources, the allocation of domestic and foreign resources should be considered. There should be both the release of domestic agricultural resources and the acquisition of foreign agricultural resources in order to obtain overall optimization. The quality of resources is dynamically changing. If domestic resources decline, becoming inferior resources, but enough high-quality foreign resources are integrated, it can still be a competitive advantage. Because different countries have different perceptions of the value of resources, the loss and acquisition of these resources is not a zero-sum game, but rather forms a value-added effect where 1 + 1 > 2, often resulting in a multi-win situation. The strength of the supply capacity is determined by the global integration of six types of resources and their compatibility with the agri-food systems.

(i) Factor resources. This category of resources includes various types of agricultural land (including arable land, orchard land, forest land, grazing land, aquaculture water areas, and so on), available water, labor, technology, and capital. Each type of resource can be quantified. Agricultural labor is a combination of worker quality and worker quantity, and the quality of agricultural laborers is expressed by the value of agricultural output per capita (at constant prices). The number of individuals involved in agriculture indicates the quantity of labor, and the product of these two variables represents labor resources. Technology is represented by productivity per unit of land.

(ii) Relevant industry resources. This category of resources mainly refers to the upstream and downstream industries of agriculture. Upstream industries include agricultural input industries such as pesticides, fertilizers, and agricultural machinery, while downstream industries mainly include agricultural product logistics and processing industries that use agricultural raw materials. These industries can be quantified by their scale of development. Agricultural product logistics depends on the rural transportation situation, i.e., the number of rural roads, and agricultural machinery production can be represented by the total horsepower output. Pesticide and fertilizer production can be measured in tons.

(iii) Demand resources. Demand resources refer to market size, which, once integrated, cannot be realistically converted into market share by other countries even if they have cost or quality advantages. The market size can be quantified, but its features are difficult to quantify. Demand resources are divided into import markets, export markets, and domestic markets for self-production and self-sale. The first two markets are affected by changes in their foreign environments.

(iv) Organization resources. Refers to various organizational forms that break through the production limitations of small farmers, such as cooperatives, family farms, industrial organizations, and social services. These organizations' features are difficult to quantify, so assuming that all organizations are homogeneous, their numbers can be used for quantification.

(v) Government resources. Domestic government support for domestic agriculture is primarily through agricultural policies and supporting funds. As agricultural policies are difficult to quantify at a given point in time, government resources are quantified using financial support funds for agriculture.

(vi) Opportunity resources. Opportunities are uncertain resources, both good and bad. Some opportunities are encountered passively and some are caught up actively. Opportunities in Porter's theory refer to major chance events, but this paper expands the scope to include uncertainties in the global political, economic, and financial environment, which have a great impact on industrial development, into the scope of opportunities. China's accession to the WTO in 2001 and the signing of RCEP at the end of 2020 are opportunities for Chinese agriculture that are not easily quantifiable. The data in this paper avoids these two big shock events from 2001-2020 and uses the composite risk index from the International Country Risk Guide database.

Grey Correlation Analysis Evaluation Method

The matching degree between the supply capacity of the agri-food systems and the integration of agricultural resources can be characterized as the correlation degree between the two. The grey correlation analysis is a multi-factor analysis technique that calculates the grey correlation degree, expressing the strength, size, and order of the relationship between factors using grey correlation sequences [19]. The basic idea of grey correlation degree analysis is to judge their relationship by comparing the geometric characteristics of sequence curves. The closer the similarity between curves, the stronger the correlation between the corresponding sequences. The opposite is also true.

The quantitative models of the grey correlation degree analysis method include Deng's correlation degree, grey B-type correlation degree, T-type correlation degree, generalized correlation degree, grey slope correlation degree, grey absolute correlation degree, C-type correlation degree, and grey Euclidean correlation degree, among others [19]. Each method has its advantages and disadvantages. Among them, the grey slope correlation degree analysis method is more suitable for temporal sequence correlation analysis with dimensional differences. The basic principle of this method is that the trend of a curve can be characterized by changes in the slope of the curve at each point. If the slopes of the corresponding curves of two sequences are nearly equal, the trend of the two curves will be almost parallel, and the correlation degree between the two sequences can be considered very high [20]. The calculation of the slope correlation coefficient is shown in Equation (1).

Slope correlation coefficient:

$$\zeta_{0i}(t)=\frac{1}{1+\left|\frac{1}{\sigma_{x_0}}\cdot\frac{\Delta x_0(t)}{\Delta t}-\frac{1}{\sigma_{x_i}}\cdot\frac{\Delta x_i(t)}{\Delta t}\right|} \tag{1}$$

where:

$\Delta x_i(t) = x_i(t) - x_i(t-1)$, $i = 0, 1, ..., m$; $\Delta t = t - (t-1) = 1$; $\frac{\Delta x_i(t)}{\Delta t}$ is the slope of the sequence x_i at time t; m is the number of data sequences compared.

Standard deviation:

$$\sigma_{x_i}=\sqrt{\frac{1}{n}\sum_{t=1}^{n}\left(x_i-\bar{x}_i\right)^2}, i=0,1,...,m, \tag{2}$$

where: n is the number of time series data.

The standard deviation reflects the overall dispersion or individual differences in a set of data. Adding this term to the equation is intended to eliminate the adverse effects when there are large differences in dimensions between the two sequences, ensuring that the data of the two sequences are of the same order of magnitude. In the $x_i(t)$ time series data, since the data at the initial moment has no slope, there is no slope correlation coefficient at the initial moment.

Using the supply capacity of the agri-food systems (x_0) as the reference data sequence, factor resource integration (x_1), organization resource integration (x_2), related industrial resource integration (x_3), demand resource (x_4), government resource (x_5), and opportunity resource (x_6) are used as comparative data sequences. The slope correlation coefficient between x_0 and x_1, x_2, x_3, x_4, x_5, and x_6 data sequences are calculated separately using Equation (1), denoted as $\zeta_{0i}(t)$, $i = (1,2,3,4,5,6)$. Since Δt in the denominator is 1, the slope is essentially the annual increase value of each resource. The correlation degree is defined as the vertical average of the correlation coefficients, and the calculation equation is shown in Equation (3). Factor resources, related industrial resources, and demand resources are composed of multiple sub-resources, and the correlation analysis process between agri-food systems supply capacity and sub-resources refers to Equations (1) and (3). The correlation degrees are sorted with the top half as the advantageous resources and the bottom half as the disadvantageous resources.

Correlation degree:

$$r_{0i}=\frac{1}{n-1}\sum_{t=1}^{n-1}\zeta_{0i}(t),\ i=1,2,...m \tag{3}$$

The horizontal average is used as the static correlation evaluation index of the supply capacity of the agri-food systems, which is the quantitative result of various resource integration, as shown in Equation (4).

$$C_s(t)=\frac{1}{m}\sum_{i=1}^{m}\zeta_{0i}(t) \tag{4}$$

To evaluate the continuity of the coordination status between the supply capacity of China's agri-food systems and the integration of agricultural resources, a dynamic correlation evaluation index of the supply capacity of the agri-food systems is set up, as shown in Equation (5).

$$C_d(t)=\frac{1}{t-1}\sum_{k=0}^{t-1}C_s(t-k), t=2,3,...n \tag{5}$$

The static correlation evaluation index of the supply capacity of the agri-food systems is calculated from the correlation degree. The greater the correlation degree, the better the matching. Otherwise, it is worse. The matching level is divided based on the following criteria: $0 \le C_s(t) < 0.4$ is a serious mismatch; $0.4 \le C_s(t) < 0.5$ is a moderate mismatch; $0.5 \le C_s(t) < 0.6$ is a slight mismatch; $0.6 \le C_s(t) < 0.7$ is a weak match; $0.7 \le C_s(t) < 0.8$ is a basic match; $0.8 \le C_s(t) < 0.9$ is a compare match; $C_s(t) \ge 0.9$ is a high match. For the dynamic correlation evaluation index, if $t_1 > t_2$ (where t_1 and t_2 are any two different time points) and $C_d(t_1) > C_d(t_2)$, this indicates that the matching relationship between the supply capacity of the agri-food systems and the integration of agricultural resources is improving [21].

2.2 Data Sources

This paper collects data from 2001 to 2020. Data such as per capita grain yield (kg/person), population (10,000 people), available water resources (10,000 tons), fertilizer production (10,000 tons), pesticide production (10,000 tons), and agricultural machinery quantity (10,000 kW) are sourced from the "China Statistical Yearbook" (http://www.stats.gov.cn/sj/ndsj/). The number of agricultural organizations (units) comes from the "China Agriculture Yearbook" (http://www.shujuku.org/china-agriculture-yearbook.html). The total mileage of rural roads (10,000 km) is from the Chinese Ministry of Transport's calendar year "Road and Waterway Transportation Industry Development Statistical Bulletin" (https://www.mot.gov.cn/fenxigongbao/hangyegongbao/). Food production value (constant US dollars), agricultural land (hectares), number of agricultural labor, agricultural per capita output value (constant US dollars), agricultural net capital stock (constant US dollars), overseas direct investment (constant US dollars), outward direct investment (constant US dollars), import of agricultural products amount (constant US dollars), export of agricultural products amount (constant US dollars), grain yield per unit area (kg/ha), and government financial support for agriculture funds (constant US dollars) are all from the Food and Agriculture Organization database (https://www.fao.org/faostat/en/#data); The global composite risk index comes from the International Country Risk Guide database (https://guides.tricolib.brynmawr.edu/icrg#s-lg-box-5809747).

3. Results Analysis

3.1 Correlation Matching Analysis between the Agri-food Systems and Factor Resources

Factor resources are the basis of agri-food systems. The per capita food quantity and per capita grain quantity are used as reference data sequences; technology, agricultural land, water supply, labor force, net capital stock, foreign direct investment, and outward direct investment are used as comparison sequences. The relevant data sequences are processed in turn using Equations (1) and (3), and according to the matching degree grading method, Table 1 is obtained as the following.

Table 1 shows that the correlation coefficients between sub-factor resources and both food and grain production increases are equal. The order of correlation degree is technology > labor force > net capital stock > agricultural land > outward direct investment > water supply > foreign direct investment. The correlation degree of all factors shows a positive matching relationship, albeit with varying degrees. From the ranking, it can be seen that technology, labor force, and net capital stock are advantageous resources, while agricultural land, water supply, and foreign investment are disadvantageous resources.

Agricultural technology is the first sub-factor to promote food and grain production. The correlation degree of food is 0.9090, and the correlation degree of grain is 0.9222, both of which are the highest level of high match, consistent with the conclusions of representative research literature [22,23]. Relatively speaking, technology has a slightly higher impact on grain than on food, indicating that the technological input for grain crops is higher than the average level of the agri-food systems. The labor force is the second sub-factor in promoting food and grain production. The labor force not only includes quantity but also quality, and labor force quality is expressed by labor productivity. Labor productivity is also part of the technology category, indicating that technology plays an all-around role in promoting food and grain production. As vegetable and fruit industries are more labor-intensive than grains, the correlation degree between the labor force and food is 0.9079, higher than that between grain and labor at 0.8717. Agricultural capital, represented by machinery and facility agriculture, is the third sub-factor to promote food and grain production, both of which are matched. However, agricultural land and water supply, as the most basic sub-factors of food output, are only ranked fourth and sixth, respectively, not because these two resources are not important, but because this study focuses on the correlation degree of annual yield increases. China's agricultural land area is basically unchanged, and water resources are more severely constrained than land resources. Therefore, their importance is only reflected in maintaining food and grain base output, and the increase part mainly relies on technology to make up for the shortage, by vigorously developing water-saving technology to reduce dependence on water resources [24], and importing agricultural products to use foreign resources through virtual land and virtual water [25]. Outward direct investment ranks fifth, and China's agricultural outward investment focuses on the agricultural industry chain [26], including logistics, processing, warehousing, finance, and R&D, with the aim of increasing control over the agriproduct supply chain and obtaining technology, which is conducive to China's focus on the comparative advantages of agricul-

Table 1. Correlation and matching between agri-food systems and factor resources.

	Technology	Agricultural land	Water supply	Labor force	Net capital stock	Foreign direct investment	Outward direct investment
Food correlation degree	0.9090	0.8572	0.6875	0.9079	0.8907	0.6365	0.8389
Food matching degree	high match	compare match	weak match	high match	compare match	weak match	compare match
Grain correlation degree	0.9222	0.8256	0.7031	0.8717	0.8586	0.6395	0.8226
Grain matching degree	high match	compare match	basic match	compare match	compare match	weak match	compare match

tural products. Outward foreign investment ranks last. Foreign direct investment has a certain effect on China's agriculture, bringing new technologies and management methods, but its correlation degree is the lowest, and both food and grain are weak matches. The reasons are twofold: first, China has restrictions on foreign agricultural investment, and second, China has a low dependence on foreign capital in agriculture. There is considerable room for improvement in China's foreign and international resources.

3.2 Correlation Matching Analysis between the Agri-food Systems and Related Industrial Resources

The per capita food quantity and per capita grain quantity are used as reference data sequences; agricultural machinery, fertilizers, pesticides, and rural roads are used as comparison data sequences. Once again, Equations (1) and (3) are used, and the matching degree grading method is used to obtain Table 2 as follows.

The correlation degree of each sub-resource to food and grain production varies, as illustrated in Table 2. For food, the order is rural roads > agricultural machinery > pesticides > fertilizers, while for grain, the order is agricultural machinery > rural roads > pesticides > fertilizers. From the ranking, it can be seen that rural roads and agricultural machinery are advantageous resources, while pesticides and fertilizers are disadvantaged resources.

The matching degrees of rural roads and agricultural machinery with food are both high, and the correlation degree of rural roads is 0.9051, slightly higher than the 0.9026 for agricultural machinery. Generally speaking, in the non-grain agri-food sector, many agricultural lands are located in remote places with complex terrain, and food output relies more on timely transportation. The correlation degree of rural roads and agricultural machinery with grain is one level lower than that with food, which is matched, and the correlation degree of agricultural machinery is 0.8640, slightly higher than the 0.8618 for rural roads. The reason for the difference in the order is that the scale effect of grain production is obvious, and the degree of mechanization is higher than the average level of agricultural machinery, especially in mechanized grain planting.

The correlation degrees of pesticides and fertilizers with food are 0.8288 and 0.8042, respectively, which are higher than the corresponding 0.8098 and 0.7860 with grain. The main reason is that from 2001 to 2020, grain planting reduced the input of pesticides and fertilizers by improving technology, while the reduction of pesticides and fertilizers in the production of vegetables and fruits was far less than that of grain planting. The correlation degrees of pesticides and fertilizers are lower, indicating that reducing pesticides and fertilizers has achieved results in reducing their negative impact on the environment.

3.3 Correlation Matching Analysis between the Agri-food Systems and Demand Resources

The capability of China's agri-food systems supply also depends on whether the food or grain produced can be absorbed by effective demand. The demand for resources can be divided into two categories: The domestic market and the international market, which can be further divided into the export and import markets. The per capita food and per capita grain are taken as reference data sequences, and the domestic market, export market, and import market are taken as comparison data sequences. By using Equations (1) and (3) again, as well as the matching degree grading method, Table 3 below is obtained.

From Table 3, it can be seen that the correlation degree of various markets with the increase in food and grain production is in the same order, which is domestic market > import market > export market. Therefore, the domestic market is an advantageous resource, while the international market is a disadvantageous resource. China's food or grain mainly meets the needs of domestic people, realizing food security and food guarantees. Therefore, the highest correlation degree reflects China's reality, and the correlation degree of food is 0.9093, higher than that of grain 0.8764. This is mainly because in China's huge reserve system, grain is the main part, and the amount of grain reserves will suppress the impact of production fluctuations on the domestic market [27]. The import market ranks second and is matched with food and grain. The types of food

Table 2. Correlation and matching between agri-food systems and relevant industry resources.

	Food				**Grain**			
	Agricultural machinery	**Fertilizers**	**Pesticides**	**Rural roads**	**Agricultural machinery**	**Fertilizers**	**Pesticides**	**Rural roads**
Correlation degree	0.9026	0.8042	0.8288	0.9051	0.8640	0.7860	0.8098	0.8618
Matching degree	high match	compare match	compare match	high match	compare match	basic match	compare match	compare match

or grain imported by China are mainly scarce resources, such as imported soybeans that are conducive to using cultivated land for more efficient varieties of wheat and corn, and using foreign resources to promote the improvement of domestic supply capacity. The correlation degree of the export market is the lowest, which indicates that the export market is not the main goal of agri-food systems supply. The correlation degree of food is 0.7082, higher than that of grain's 0.6955, with matching degrees of the basic match and weak match, respectively. The reason for the difference is that there is an economic interest in supplying vegetables, fruits, aquatic products, and other foods to foreign countries. Grain lacks comparative advantages and obviously has no driving force for foreign supply interests, so the correlation degree of the food export market is greater than that of grain.

3.4 Correlation Matching Analysis between the Agri-food Systems and Resource Integration

Using Equation (4), the sub-factor resources are integrated into the factor resource correlation, related industry resource correlation, and demand resource correlation. Using Equations (1) and (3), the correlation degrees of organization resources, government resources, and opportunity resources are respectively analyzed by using grey correlation analysis with the agri-food systems supply capability. Finally, the six types of resources are integrated into a static evaluation index by using Equation (4), and the evaluation is divided according to the matching level. The detailed results are shown in Table 4.

As shown in Table 4, the correlation degree of six types of resources with the increase in food and grain production is in different orders. For food, the order is government resources > related industry resources > organization resources > factor resources > demand resources > opportunity resources; for grain, the order is government resources > factor resources > related industry resources > organization resources > demand resources > opportunity resources. The reason for the difference in ranking is the change in the ranking of elemental resources. It can be inferred that government resources and related industry resources are advantageous resources, organization resources and factor resources are uncertain, and demand resources and opportunity resources are disadvantageous resources.

From the perspective of food output growth, among the six resources, the government resource has the highest correlation with food production, with a correlation coefficient of 0.8999. The government resources are reflected in the financial support for agriculture. The financial support mainly includes fund investments in infrastructure construction in agriculture, forestry, and water conservancy, comprehensive development of agriculture, agricultural technology, and agricultural production, and extends to investments in rural construction, basic welfare for farmers, and social security. This shows that the role of the Chinese government in promoting food and grain growth is significant. Related industry resources rank second, with correlation coefficients of 0.8602. Mechanical manufacturing, pesticide and fertilizer production are the advantages of China's industrial manufacturing industry. The development of transportation roads is also the result of China's emphasis on building roads first to become rich. Organization resources rank third, and agricultural economic organizations are China's efforts to overcome the limitations of individual farm production by improving food production through various forms of organization such as cooperatives, family farms, industrialized organizations, and socialized services, etc. Factor resources rank fourth because natural resources are China's disadvantage. Demand resources rank fifth, mainly due to the lack of influence on overseas markets. Opportunity resources rank last, and the opportunities here refer to the international environment for the development of China's agri-food systems, mainly involving the three dimensions of politics, finance, and economy. China made significant concessions in protecting agriculture to join the World Trade Organization (WTO), and the international environment for agriculture development has been relatively harsh [28], which is the reason why the correlation coefficient between food production and opportunity resources is the lowest. From the perspective of static matching, except for the weak match of opportunity resources, all the others have the compare match, and comprehensive matching is the compare match. China's global integration of agricultural resources is relatively supportive of China's agri-food systems development.

Table 3. Correlation and matching degree between agri-food systems and demand resources.

	Food			**Grain**		
	Domestic market	**Export market**	**Import market**	**Domestic market**	**Export market**	**Import market**
Average correlation degree	0.9093	0.7082	0.8737	0.8764	0.6955	0.8649
Matching degree	high match	basic match	compare match	compare match	weak match	compare match

Table 4. Correlation and matching between agri-food systems and resources integration.

	Factor resources	Relevant industry resources	Demand resources	Organization resources	Government resource	Opportunity resource	Static correlation evaluation index
Food correlation degree	0.8445	0.8602	0.8304	0.8566	0.8999	0.6954	0.8312
Food matching degree	compare match	compare match	compare match	compare match	compare match	weak match	compare match
Grain correlation degree	0.8330	0.8304	0.8123	0.8239	0.8663	0.6882	0.8090
Grain matching degree	compare match	compare match	compare match	compare match	compare match	weak match	compare match

From the perspective of grain production, among the correlation degrees from 2002 to 2020, government resources ranked first, and direct subsidies for grain finance accounted for an important proportion of financial support for agriculture, mainly including four kinds of subsidies: direct subsidies for grain planting, high-quality seed subsidies, subsidies for the purchase of agricultural machinery, and comprehensive subsidies for agricultural inputs. These government resources greatly affect the production cost of grain and the enthusiasm of grain farmers. Unlike food production, grain production has a higher degree of correlation with factor resources, jumping from the fourth place in food production to the second place, because grain is a land and water intensive crop, far higher than the requirements for land and water resources in non-grain agriculture. The reasons for the ranking of other related industries, organization resources, demand resources, and opportunity resources are similar to those of food production. From the perspective of average static matching, except for the weak matching of opportunity resources, all the others have a relatively good correlation. Whether from the perspective of food or grain production, China's global integration of agricultural resources is relatively supportive of the development of China's agri-food systems.

The annual static correlation evaluation index obtained from the calculation process in Table 4 was utilized to create Figure 2, which illustrates the fluctuations in the static correlation evaluation index for food and grain production.

Figure 2 displays the annual static correlation evaluation index from 2002 to 2020. Overall, the annual static correlation evaluation index of grain growth is similar to that of food growth, and the difference between them is not significant. However, there are two particular years. One is in 2003 when the evaluation index of grain growth decreased, the evaluation index of food growth increased, and the difference between the two was very large. The other is 2019, where the situation was the opposite of that in 2003. The reason for the difference in 2003 may be the result of China's comparative advantage in agriculture being reversed [29]. According to the World Trade Organization (WTO) caliber, China's agricultural trade was in an international surplus until 2003, after which it turned into a persistent deficit [30]. In 2003, China's industrialization reached the mid-stage, and its comparative advantage had been established in the international division of labor. A large amount of agricultural land was occupied, marking

Figure 2. Static evaluation of the correlation between agri-food systems and resources integration.

the transition of agriculture from a comparative advantage to a comparative disadvantage. The comparative advantage within agriculture also changed. The comparative disadvantage of crops such as grain, which are intensive in land density, became more prominent, while the comparative advantage of non-grain crops became increasingly effective. After the development of industry, the Chinese government used the financial power of the industry to support agriculture, and then tax and fee reforms and related policies were introduced to prevent further deterioration of agriculture. The situation in 2019 was the result of the Sino-U.S. trade war in China's agriculture. China retaliated against the US trade war, increased tariffs starting in 2018, and significantly increased them in 2019, causing a reduction of more than 70% in the import of 99% of agricultural products from the US, including soybeans, sorghum, livestock products, corn, and grains, forcing China to increase imports from other countries. At the same time, China announced policies to vigorously increase the planting of grain crops, squeezing out non-grain agricultural resources. Also in 2019, African swine fever broke out in many parts of China, causing a decrease in non-grain crop production. With the reduction of tariffs between China and the US and China's adaptation to shocks, agriculture began to recover normally.

By using Equation (5) to convert the annual static correlation evaluation index to the dynamic correlation evaluation index, the trend curves of food and grain production are shown in Figure 3.

The dynamic correlation evaluation index can reflect the trend of change. From Figure 3, the shapes of the trend curves of food and grain products have been similar since 2003, but the trend of change is slightly different. The curve of food production fluctuated upward from 2002 and gradually peaked in 2014, then began to trend downward, indicating that the support of agricultural resource integration in China's agri-food systems is weakening. The curve of grain production drastically declined in 2002, then fluctuated upward, reaching a peak in 2015, and remained in a stable fluctuation state without a continuous downward trend. Unlike food, the dynamic correlation evaluation index of grain has been lower than that of food since 2003, indicating that in the integration of agricultural resources, the effect of food production on the supply capacity of the agri-food systems is greater than that of grain, and demonstrating that the benefits of food production are greater than the benefits of grain production.

4. Discussion

The impact mechanisms of the six categories of agricultural resources on the agri-food systems are different. Factor resources directly affect food production, while related industrial resources help food production from the upstream and downstream aspects. Demand resources allow for the distribution of final food products, while organization resources influence food production efficiency. Government resources regulate the allocation of food production resources, and opportunity resources affect food production from the perspective of uncertainty [31]. In the specific impact pathways and processes, the impact of factor resources and related industrial resources is relatively clear. However, the impact of demand resources, organization resources, government resources, and opportunity resources is relatively vague or even unknown. Therefore, the mutual relationship of the agri-food system composed of agricultural resources is extremely complex. It is difficult to clarify the logical relationship between various impact mechanisms and it belongs to a typical gray area. Some scholars have attempted to use the theory of complex system co-evolution to study the relationship between water resources, energy, and food systems without involving economic and political factors [32]. However, the scope of resources in this paper is much larger, and the interweaving of known and unknown relationships is more

Figure 3. Dynamic evaluation of the correlation between agri-food systems and resources integration.

complex, so it is difficult to use the co-evolution method of complex systems. In addition, the various methods in the existing literature are mainly applicable to make one-way influence research, but food and resources are interactive influence relationships. Resources determine the output of food, and food requirements affect the allocation and utilization of resources. Gray correlation method is similar to the correlation analysis of statistics, which can be applied to both one-way and two-way relationships. Therefore, this paper adopts the grey correlation method to study the matching relationship.

Expanding the view of agricultural resources from natural resources to economic and social resources that are needed for food supply is a new attempt. The integration of natural resources and economic and social resources involves not only the current natural potential of food supply but also the social implementation level of that potential. It is advantageous to discover the path to improving the supply capacity of the agri-food systems by the direction of integrating both natural resources and economic and social resources.

From the results of the matching research between resource integration and the supply capacity of agri-food systems, this paper realizes the combination of the resource part and output part of agri-food systems, thereby expanding the evaluation method of food supply capacity. The two parts are currently matched but there is room for improvement. It not only conforms to the current situation of China's agri-food systems maintaining food security, but also indicates that there is still a need to improve the state of demand resources and opportunity resources internationally and promote the transformation of organization resources and factor resources towards a positive direction.

Agriculture in China encompasses both food and non-food production (such as cotton, tobacco, hemp, silk, wood, etc.). In this paper, the term agricultural resources refers to the entire agricultural sector, including the unused and idle parts, which is a broader scope than the resource base of agri-food systems. The slope correlation analysis is a relative index. When the proportion of food resources, non-food resources, and idle resources remains basically unchanged, the problem of inconsistent statistical scope can be partially eliminated. However, if the proportion of these three resources changes significantly, it will affect the accuracy of the correlation. In addition, the uncertainty factors that China faces, such as natural disasters and climate, are obviously external opportunities for agricultural development, but are difficult to quantify. Their impact results are implicitly based on unit area yield, affecting the accuracy of technical quantification.

5. Conclusions

Based on the resources integration theory, this paper evaluates the matching status between the supply capacity of the agri-food systems and resources using the gray correlation method. The following conclusions are drawn:

Overall, agricultural resources are the compare match (correlation between 0.8 and 0.9) with the development of China's agri-food systems, but there is still room for improvement to achieve a high match (correlation greater than 0.9). Among the six categories of resources, government resources and related industrial resources are advantageous resources, while organization resources and factor resources are uncertain, and demand resources and opportunity resources are disadvantaged resources.

As can be seen from the previous evaluation, most of the domestic resources are advantageous resources because their sovereignty belongs to China, and thus they are highly controllable and correlated. Agricultural land and water supply, limited by natural resources and beyond human capacity, become passively disadvantaged resources. Pesticides and fertilizers, because of ecological and sustainable development requirements, become actively disadvantaged resources. All foreign resources are disadvantaged, such as opportunity resources, foreign investment, and international markets, due to China's insufficient ability to control foreign resources.

The view of big food is beneficial to reducing dependence on factor resources, especially arable land and water resources. The overall correlation of food production increases in the agri-food systems is higher than that of grain production increases, indicating that the efficiency of obtaining nutrition through various agricultural resources is higher than that of relying on grain. Achieving food security under the big food view alleviates pressure on grain production as well as arable land and water resources.

For other populous countries aiming to ensure food self-sufficiency, the theoretical and analytical framework of this paper is equally applicable, helping to identify the various types of advantageous or disadvantageous resources, so as to formulate policy measures to ensure the sustainable development of their agri-food systems.

Author Contributions

Shaowen Yang: conceptualization, methodology, validation, formal analysis, writing draft; Ping Wang: methodology, validation, data curation, writing draft, writing review; Zhaogang Fu: formal analysis, data curation, writing review.

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Data Availability

The data are available from the corresponding author upon reasonable request.

Conflict of Interest

All authors disclosed no conflict of interest.

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RESEARCH ARTICLE

Does Informatization Cause the Relative Substitution Bias of Agricultural Machinery Inputs for Labor Inputs? Evidence from Apple Farmers in China

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Abstract: The change of information scenario may change the market transaction cost of different factors, thus changing the relative price of factors and inducing the substitution of production factors, but there is no research to prove this. Therefore, this study takes labor-saving technology (mechanical substitution of labor) as an example, evaluates informatization from three aspects of information technology access, information technology application and information literacy comprehensively, and uses the probit model and CMP method to analyze whether informatization causes the substitution of agricultural machinery inputs for labor inputs and its heterogeneity. The results show that informatization has a significant negative impact on farmers' choice of labor-saving technology, and the result is robust at the regional level, but the negative impact of informatization on farmers' choice of labor-saving technology in the eastern region is smaller than that in the western region. The level of information literacy has the largest negative impact on farmers' choice of labor-saving technology, followed by the level of access to information technology, and the level of application of information technology has the smallest impact. The study concludes that informatization has not led to the significant substitution of labor by machinery in apple production. Thus, the results are important for enriching the theory of induced change in agricultural technology in the context of informatization.

Keywords: Information technology access; Information technology application; Information literacy; Labor-saving technology; Agricultural factor substitution

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1. Introduction

The theory of induced technological change has been widely used to analyze agricultural technological change and adaption [1-3]. Its main view is that the change in the relative price of factors caused by the change in resource scarcity will induce agricultural factor substitution. In production, micro-enterprises will seek relatively abundant factors to replace relatively scarce elements through the market mechanism, and apply technologies to save relatively scarce elements in order to maximize the marginal revenue of total factor input. Since the 1990s, the development of informatization based on ICT (Information Communication Technology) has broken the barrier of information asymmetry [4], which effectively promoted the innovation of agricultural market operation mechanism [5,6], the reform of the agricultural factor market and the improvement of agricultural public service capacity, and provided a good market environment for the realization of optimal resource allocation in a wide range. Theoretically, under the dual constraints of factor endowments and production conditions, the information asymmetry between the production and management units and different factor retailers is different. As a result, farmers participate in different factor markets and their transaction costs are different. In this case, the relative price changes of factors may be caused by informatization, which has a different impact on the price changes of different factors. Will informatization then lead to the substitution bias of agricultural machinery inputs for labor inputs? The answer to this question is important for the formulation or adjustment of factor marketization policies under the background of informatization and the promotion of "Internet+" agricultural upgrading.

Agriculturally induced technology includes labor-saving technologies and land-saving technologies from the perspective of the relative scarcity of factors. In literature, empirical studies on agricultural induced technology mainly focus on the importance of factor endowment. However, the existing studies show obvious regional characteristics due to the differences in factor endowment structure in different regions and different historical stages. For example, Hayami and Ruttan [7] took the example of agriculture in Japan and the United States as an example, and found that due to the difference in factor endowment between America and Japan, American agriculture was based on labor-saving technologies, while Japanese agriculture was based on land-saving technologies. On this basis, some scholars have also studied the relationship between factor endowment structure and agricultural technology change in China [3,8,9]. For example, Zheng et al. [10] found that differences in farmers' technology choice preferences are due to asymmetries in different types of farmers' endowment constraints and characteristics of different agricultural technologies. However, some scholars have found that the impact of farmers' endowments on the choice of agricultural technology had general similarities and differences at the same time [11]. With the application of new institutional economics and information economics in the agricultural field, some scholars have started to pay attention to the impact of transaction costs on the choice of agricultural production technology [12]. For example, Zhang et al. [13] found that the transaction cost is an important factor limiting the extensiveness of technology adoption by farmers. Some scholars also analyzed the influence of information acquisition on the choice of production technology [14,15]. For example, Luh et al. [16] investigated the influence of information acquisition on farmers' choice of transgenic seed technology in Taiwan. They found that information acquisition significantly increased farmers' likelihood of choosing transgenic technology. In addition, some scholars focused on the influence of information acquisition ability on new technology choices [17].

Based on the above analysis, we can see that the research on the relationship between informatization and production technology choice is still worth paying attention to, so as to overcome the shortcoming that the existing research focuses on taking a certain technology as an example and lacks in-depth analysis of the impact of informatization on farmers' technology selection behavior induced by factor scarcity from the perspective of production factor structure. In addition, the existing research only focuses on the influence of one aspect of information acquisition mode or information acquisition ability on technology selection, and lacks a comprehensive consideration of the informatization level from multiple perspectives and a comparative analysis of informatization in different dimensions. Theoretically, both information acquisition mode and information acquisition ability are important factors in determining farmers' information abundance for production decision-making. Based on this, this paper takes labor-saving technology as an example, comprehensively evaluates the informatization level from three dimensions of information technology access, information technology application and information literacy, and analyzes whether informatization causes the substitution bias of agricultural machinery inputs for labor inputs. The reason for choosing labor-saving technology is that apple is a labor-intensive crop, under the dual constraints of the continuous transfer of agricultural labor to non-agricultural industries and the ageing of agricultural labor, the labor cost is in a continuous upward trend, and the labor may be in a state of relative scarcity for a long time.

2. Theoretical Analysis and Research Hypothesis

2.1 Conceptual Definition and Measurement of Informatization

In 1963, the Japanese sociologist Tadao Umesao first put forward the idea of informatization in his article entitled "Information Industry". He thought that informatization was the general term for the modernization of communication, computerization and rationalization of behavior. Since then, domestic scholars have done a lot of research on the definition of informatization. The First National Informatization Work Conference held in 1997 defined informatization as "the historical process of cultivating and developing new productivity represented by intelligent tools and making it benefit the society". In 2006, the General Office of the CPC Central Committee and the General Office of the State Council issued the National Informatization Development Strategy for 2006-2020, which defined informatization as "the historical process of fully utilizing ICT to develop and utilize information resources, promote information exchange and knowledge sharing, improve the quality of economic growth, and promote the transformation of economic and social development". The Informatization Statistical Evaluation Research Group of the Institute of statistics of the National Bureau of Statistics (2011) defined informatization as "the process of transforming, reorganizing or reorienting the socio-economic structure and industrial structure by using high-tech information technology to improve the information and knowledge content of products and economic activities, and then promoting the whole society to achieve a higher level, more organized and more efficient economic development". Overall, the current discussion on the connotation of informatization focuses only on the access to and application of information technology, which has been verified in the literature on assessing the level of informatization.

In the process of the integrated development of informatization and agricultural modernization, the exploration of informatization has gradually extended to the level of agriculture, rural areas and farmers, and the concepts of agricultural informatization [18,19], rural informatization [20,21] and farmer informatization [22] have been put forward. Due to the obvious differences in the connotation and research methods of informatization among different research topics, it is necessary to clarify the research scope and boundary of informatization before the research. From the perspective of the research topic and research object, this paper mainly focuses on the analysis of farmers' informatization level. In the process of developing a digital society, inequality in the distribution of information infrastructure, the development and application of digital technology, and the ability to acquire and process digital information leads to the unequal enjoyment of the dividends brought by ICT among different social groups, resulting in the phenomenon of "information poverty" and "information differentiation" [23]. The key to eliminating information poverty and differentiation is to improve the information literacy of the whole population and to enhance the ability of social members to seek, assimilate and use information [24]. Therefore, in addition to considering information technology access and application, information literacy should be an important part of assessing farmers' informatization levels.

Based on the research idea of Busindeli [25] on the media preference for agricultural information acquisition and dissemination, this paper designs the informatization measurement system in terms of information availability and information accessibility, where information availability reflects the level of farmers' access to information, and information accessibility reflects the level of farmers' utilization of information. In terms of the information diffusion process, efficient farm information in the information environment needs to cross two thresholds for final use in farmers' production decisions (as shown in Figure 1). The first threshold determines whether farmers can obtain the information and the amount of information, i.e. information availability, and the second threshold determines whether farmers can effectively absorb and use the information and the amount of information absorbed and used, i.e. information accessibility. Thus, it is clear that the level of information ultimately used in farmers' production decisions is a comprehensive consideration of information availability and information accessibility.

Based on the above analysis, the informatization studied in this paper includes information technology access, information technology application and information literacy. Among them, information technology access mainly refers to farmers' access to smartphones, computers, mobile internet and fixed broadband internet [4]; information technology application mainly refers to the extent to which farmers use ICT to obtain information on agricultural operations; information literacy mainly refers to farmers' information awareness and the ability to search, judge, select, absorb and use the required information and apply it to agricultural production by ICT tools [26].

2.2 Research Hypothesis

According to the theory of induced technological

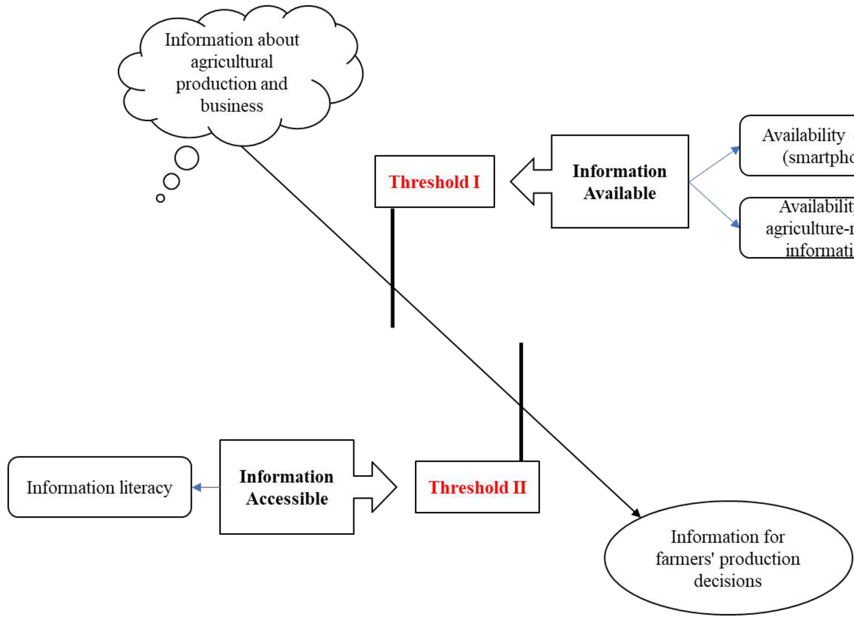

Figure 1. Theoretical framework of the informatization measurement system.

change, the change in the relative price of factors caused by the change in resource scarcity will induce technological change [7]. Under the assumption that the factor market is effective, the change in the relative price of production factors can fully reflect the scarcity degree of scarcity of production factors, and micro-production units will use the market mechanism to realize the substitution of cheap and relatively abundant factors for expensive scarce elements, and choose the technology of saving the use of relatively scarce elements [27], so as to eliminate or partially eliminate the restriction of relatively scarce production factors on the development of agriculture. According to Hicks' definition of technology type, the induced technology of factor scarcity can be divided into two categories, including labor-saving technology and land-saving technology. The former aims to expand the cultivated area per unit of labor force or reduce the labor input per unit of land area, while the latter aims to increase the output per unit of the land area [28,29].

From the perspective of the production chain, apple is a typical labor-intensive crop, and labor is more scarce than land or capital elements, especially in the context of urbanization and the rising price of agricultural labor. This problem is more prominent. Therefore, micro production units tend to use capital to substitute labor, and this kind of substitution is first realized through mechanization [30]. Specifically, if the labor factor input per unit area is relatively less than the mechanical factor input per unit area, the technology type is defined as a labor-saving technology, and if not, it is a labor-intensive technology.

Based on the above analysis, we suppose that farmer i has fixed land endowment A_0 and labor endowment L_0, and only input land, labor and machinery in the apple production process. Further assuming that the input cost of land factor is constant, then the output and production cost of apple depend on the factor input ratio of labor and machinery, i.e. the total income R_i and total cost C_i of apple production are the functions of relative factor bias. Assuming that the relative factor bias of farmer i is Tb_i, then the optimal decision function of farmers based on the maximization of the net income effect is as follows:

$$MaxU_{Tb_i} = U_i\left[R_i(Tb_i) - C_i(Tb_i)\right] \tag{1}$$

Referring to the existing research results, we further assume that farmers have a fixed risk aversion preference and that apple planting income follows a normal distribution, and farmers' expected utility function can be expressed as an increasing mean variance standard concave function [31]. Then, under the condition of maximizing the net income effect, the optimal decision function of farmers can be extended as follows:

$$\underset{Tb_i}{Max}\, U_i(R_i, Tb_i) = E(R_i) - \frac{1}{2}\varsigma_i \operatorname{var}(R_i) - C_i(Tb_i) \tag{2}$$

In formula (2), $E(\cdot)$ is the mean function, $\operatorname{var}(\cdot)$ is the variance function and ς_i is the risk preference of farmer i.

On this basis, the total revenue of apple production is defined as:

$$R_i(Tb_i) = p_i q_i A_i + p_i A_i (Z_i + Tb_i)\mu_i \tag{3}$$

In formula (3), p_i is the apple selling price of farmer i; q_i is the apple yield per unit area of farmer i; A_i is the apple planting area of farmer i; Z_i is the characteristics of households and head of households; Tb_i is the technology selection bias of farmer i; μ_i is the random variable to measure environmental impact, which meets $\mu_i \sim N(1, \sigma^2)$; $A_i p_i (Z_i + Tb_i) \mu_i$ refers to the relative income change of agricultural production caused by the relative change of factor output rate measured by market price.

Sadoulet and de Janvry [32] found that it was not necessary to estimate the input demand and output supply system under transaction costs. Thus, our assumption is that farmers are only constrained by transaction costs when participating in factor markets. According to the research method of Key et al. [33], transaction cost is further divided into fixed transaction cost and variable transaction cost. Fixed transaction cost does not change with the change of transaction volume, including information search cost, negotiation cost, monitoring and execution cost, while variable transaction cost increases with the increase of transaction volume, including transportation cost and other costs related to incomplete information [31]. Assuming that the fixed transaction cost and unit variable transaction cost faced by farmer i due to technology selection bias are FTC_i and VTC_i respectively, then the total apple production cost of farmer i can be defined as:

$$C_i(Tb_i) = C_i^0 + A_i Tb_i (P_i^{lm} + VTC_i) + FTC_i \quad (4)$$

In formula (4), C_i^0 represents the land input cost of farmer i, and P_i^{lm} represents the input price ratio of labor and machinery when farmer i prefer technology selection bias.

By substituting formula (3) and formula (4) into formula (2), the optimal decision-making function of maximizing net income utility considering the transaction cost of farmers' participation in the factor market is obtained as follows:

$$\underset{Tb_i}{Max}\, U_i(R_i, Tb_i) = A_i p_i q_i + A_i p_i (Z_i + Tb_i) - \frac{\varsigma_i}{2} A_i^2 p_i^2 (Z_i + Tb_i)^2 \sigma_i^2 - C_i^0 - A_i Tb_i (p_i^{lm} + VTC_i) - FTC_i \quad (5)$$

Based on the above analysis, we attempt to introduce the informatization level into the formula (5). On the one hand, informatization can effectively alleviate the information asymmetry between farmers and factor retailers, make up for the lack of market information, and contribute to reducing the cost of farmers' search for factor market information, the cost of negotiation with factor retailers and the cost of supervision [34]. On the other hand, informatization can reduce farmers' sensitivity to variable transaction costs and increase market transaction efficiency [35]. Thus, assuming that the informatization level of a farmer i is I_i, the fixed transaction cost and variable transaction cost of biased input can be further defined as follows:

$$FTC_i = \psi(I_i; Z_\mu, Z_i), \text{ s.t. } \partial FTC_i / \partial I_i < 0 \quad (6)$$

$$VTC_i = \gamma(I_i) d_i^2, \text{ s.t. } \partial \gamma(I_i) / \partial I_i < 0 \quad (7)$$

In formula (6) and formula (7), Z_μ are the variables that affect farmers' fixed transaction costs of biased inputting; $\gamma(\cdot)$ is the sensitivity function of farmer i to variable transaction costs of biased inputting; and d_i is the distance between farmers and the factor market.

Furthermore, by substituting formula (6) and formula (7) into formula (5), the optimal decision-making function of farmers' biased inputting is obtained as follows:

$$\underset{Tb_i}{Max}\, U_i(R_i, Tb_i) = A_i p_i q_i + A_i p_i (Z_i + Tb_i) - \frac{\varsigma_i}{2} A_i^2 p_i^2 (Z_i + Tb_i)^2 \sigma_i^2 - C_i^0 - A_i Tb_i (p_i^{lm} + \gamma(I_i) d_i^2) - \psi(I_i; Z_\mu, Z_i) \quad (8)$$

The first derivative of technology selection bias can be obtained as follows:

$$\frac{\partial U_i}{\partial Tb_i} = A_i p_i - \varsigma_i A_i^2 p_i^2 (Z_i + Tb_i) \sigma_i^2 - A_i (p_i^{lm} + \gamma(I_i) d_i^2) = 0 \quad (9)$$

Then, the optimal technology selection bias Tb_i^* can be calculated as follows:

$$Tb_i^* = \frac{p_i - (p_i^{lm} + \gamma(I_i) d_i^2)}{\varsigma_i A_i p_i^2 \sigma_i^2} - Z_i \quad (10)$$

According to formula (10), we can see that apple growers' technology selection bias depends on apple's sale price p_i, the price ratio of labor and machinery input p_i^{lm}, informatization level I_i, distance between farmers and factor market d_i, farmer's risk preference ς_i, apple planting area A_i, the variance of environmental impact σ_i^2, family characteristics and individual characteristics of the household head Z_i.

Overall, informatization changes the relative prices of labor and machinery elements by affecting the transaction costs of farmers participating in the factor market, leading farmers to choose relatively abundant factors to replace the relatively scarce ones, thus forming a technology selection bias (Figure 2). Based on the above analysis, the research hypothesis is proposed as follows:

Hypothesis: Because of the uncertainty about the relative size of the impact of the development of informatization on the prices of machinery and labor factors, informatization may induce farmers to choose labor-saving technology or labor-intensive technology.

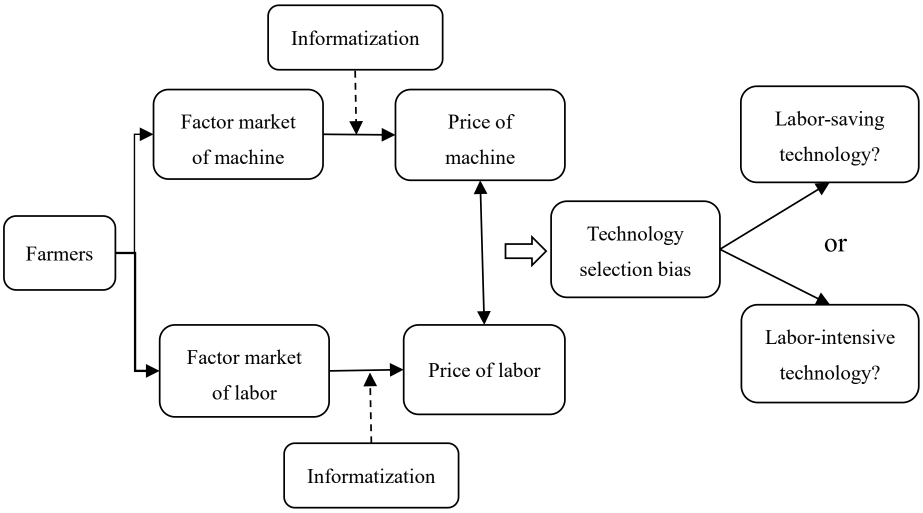

Figure 2. Theoretical framework of how informatization causes the substitution of factors inputs.

3. Methodology

3.1 Data

The data used in this paper are from the field survey of apple growers in Shandong, Shaanxi and Gansu by the research team of the National Apple Industrial Economy Research Office in July and August 2018. The multi-stage sampling method was adopted in this survey. In the first stage, Shandong, Shaanxi and Gansu were selected as the sample provinces according to the difference in regional informatization level by using typical sampling and stratified sampling methods. In the second stage, six counties are selected according to the concentration level of the apple industry by using a typical sampling method. In the third stage, three towns were selected from each sample county by using a simple random sampling method. In the fourth stage, two villages were selected from each sample town by using a simple random sampling method. In the fifth stage, 20-21 farmers were selected from each sample village by using a simple random sampling method. In this survey, 744 questionnaires were collected through face-to-face interviews. After excluding the samples with inconsistent answers or important missing variables, 727 questionnaires were collected through face-to-face interviews. After excluding the samples with inconsistent answers or important missing variables, 727 questionnaires were valid and the effective rate was 97.72%. The sample distribution area is shown in Figure 3.

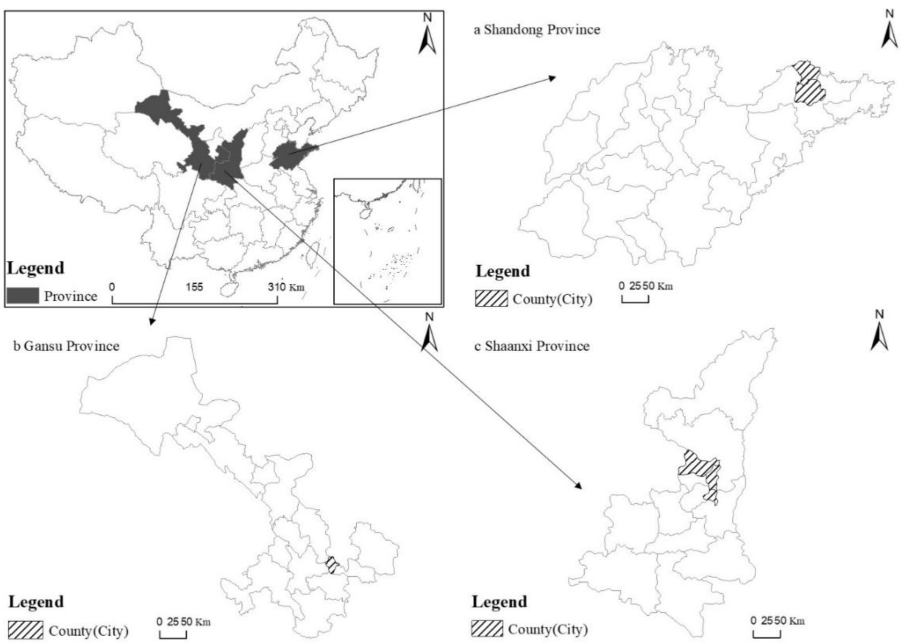

Figure 3. Sample distribution.

3.2 Model

In the theoretical analysis, the induced technology of factor scarcity can be divided into labor-saving technology and land-saving technology. Considering the labor-intensive characteristics of apple production, this paper takes labor-saving technology as an example for empirical analysis. In particular, the relative bias of factor inputs is used to define the technology choice behavior of farmers, i.e. the type of technology in which the labor factor input per unit area is relatively larger than the mechanical factor input per unit area is defined as labor-intensive technology. The type of technology with labor factor input per unit area greater than mechanical factor input per unit area is defined as labor-intensive technology, while the opposite is defined as labor-saving technology [36,37]. Referring to the existing research methods [38], the calculation formula of the bias of labor-saving technology is as follows:

$$Tb_i = (m_i / M)/(l_i / L) \tag{11}$$

In formula (11), m_i refers to the mechanical input per unit area of farmer i; M represents the average mechanical element input per unit area of the whole sample farmers; l_i represents the labor factor input per unit area of farmer i; L represents the average labor factor input of the whole sample farmers. If $Tb_i > 1$, it indicates that farmers prefer labor-saving technology; if $0 < Tb_i < 1$, it indicates that farmers prefer labor-intensive technology; if $Tb_i = 1$, it indicates that farmers prefer neutral technology.

According to formula (11), we found that the technical selection bias index of sample farmers is not equal to 1. Therefore, the factor scarcity induced technology selection behavior was defined as a binary variable T_i. If the technology selection bias index T_i of farmer i was greater than 1, the value T_i was 1, indicating that farmers choose labor-saving technology; if farmers' technology selection bias index T_i of farmer i was between 0 and 1, the value T_i was 0, indicating that farmers chose labor-intensive technology. Based on this, the Probit model was used to analyze the impact of informatization level on farmers' factor scarcity induced technology selection behavior. The benchmark model is set as follows:

$$\begin{aligned} Prob(T_i = 1) = \beta_0 + \beta_1 I_i + \beta_2 p_i + \beta_3 p_i^{lm} + \beta_4 d_i + \beta_5 A_i \\ + \beta_6 \varsigma_i + \beta_7 Z_i + \beta_8 \sigma_i^2 + \nu \end{aligned} \tag{12}$$

In formula (12), I_i refers to the informatization level of farmer i; p_i represents the apple sales price of farmer i; p_i^{lm} represents the input price ratio of labor and machinery elements of farmer i; d_i represents the distance between farmer i and the factor market; ς_i represents the risk preference of farmer i; A_i represents the apple planting area of farmer i; and represents the apple business area of farmer i; σ_i^2 represents the variance of environmental impact; Z_i represents the characteristics of the family and the head of household. $\beta_1 \sim \beta_8$ are the parameters to be estimated; ν is the random error term, and satisfies $\nu \sim (1, \sigma_\nu^2)$. In the process of model estimation, the significance and direction of β_1 to judge the influence of informatization level on farmers' factor scarcity induced technology selection behavior.

3.3 Variables Setting and Description

Based on the conclusions of the theoretical analysis above, whether farmers choose the labor-saving technology or labor-intensive technology depends on the level of informatization, the apple selling price, the price ratio of labor and machinery factor input, the distance between farmers and the factor market, the size of apple plantation, the risk preference, the characteristics of the family and the head of the household, the characteristics of the production environment. However, the causality remains to be tested. On the basis of previous studies, the specific variables are defined and explained in Table 1.

(1) Dependent variable: In this paper, whether or not the farmer chooses labor-saving technology is used to assess labor and machinery substitution bias. Combined with the technology selection bias index, it is defined as a binary variable. Specifically, if the farmer chooses labor-saving technology, the value is 1; if the farmer chooses labor-intensive technology, the value is 0.

(2) The key independent variable: the level of Informatization. Most of the existing studies use the ICT penetration rate as a proxy variable for informatization [4], which focuses on the means of information acquisition, but does not fully consider the degree of farmers' information utilization. Therefore, in this paper, we measure farmers' informatization level from three aspects: information technology access level, information technology application level and information literacy level. The specific steps are as follows: First, we select "whether to access smartphones", "whether to access mobile Internet", "whether to access computers" and "whether to access fixed broadband Internet", and use the "entropy weight method" to measure the information technology access level; select "the degree of agricultural information obtained by mobile network" and "the degree of agricultural information obtained by using fixed broadband Internet", and use the "entropy weight method" to measure the information technology application level. Second, the principal component analysis method is used to measure the information literacy level from five aspects: information awareness, information acquisition ability, information evaluation ability, information application ability and information sharing ability. Third, to comprehensively evaluate the informatization level, the entropy weight method is used to calculate the weight of information access level, information technology application level and information literacy level.

(3) Other controlled variables. 1) Price factors, including apple selling price and the input price ratio of the labor-machinery factor. Since it is known that apple selling price is endogenous, in order to eliminate the influence of endogeneity on the estimation results, this paper uses the average apple selling price of the village as a proxy variable for individual apple prices. 2) Distance between farmers and factor market. In this paper, we focus mainly on the labor and machinery markets. Since the distance between the two-factor markets cannot be accurately measured, this paper chooses the distance between farmers and the nearest farm factor market as a proxy variable. 3) Apple farm size and farmers' risk preferences. Apple is a perennial crop, and farmers' production factor input is mainly concentrated on fruit trees during the fruit-bearing season. Therefore, in this paper, apple orchard area in the fruiting season is used to represent the farm size of apple farmers. In the questionnaire, the question was designed as follows: "If there was a new apple planting technology, how would you adopt it? (1 = not to adopt; 2 = to adopt according to the situation of others; 3 = to decide after a trial on a small area; 4 = to adopt actively)". 4) Characteristics of the family and the household head. The individual characteristic variables of the head of the household include age, years of education and experience in cultivation; the characteristic variables of the family include the proportion of agricultural labor and total household income. 5) Production characteristics and environmental conditions. In combination with apple production characteristics, the proportion of irrigated area, age of apple trees, planting density and site conditions were selected to measure apple production characteristics and environmental conditions. In particular, due to the differences in planting time and structural layout in different plots, the measurement of apple tree age and planting density is at the mean level. Site conditions are represented by regional virtual features, and Gansu Province is taken as the reference group.

Table 1. Variable selection, definition and description.

Variables	Definition and description	Min	Max	Mean
Dependent variable				
Technology selection bias (Substitution of mechanical and labor factors)	Binary variable; 1 = labor-saving technology, 0 = labor-intensive technology	0	1	0.44
Independent variables				
The level of informatization	Informatization index based on "entropy weight method"	0.11	3.79	1.39
Price				
Apple selling price	The average price of apples sold in villages (yuan/kg)	1.13	4.43	2.21
Input price ratio of the labor-machinery factor	Labor factor input average price/mechanical factor input average price	0	259.55	8.94
Distance between farmers and factor market	Distance from factor market to nearest agricultural material sales market (km)	0.01	100	5.01
Apple farm size	Apple planting area in the fruit bearing period (mu)	1	60	7.38
Farmers' risk preference	1 = not to adopt; 2 = to adopt according to the situation of others; 3 = to decide after trial in small area; 4 = to adopt actively	1	4	2.83
Characteristics of the family and household head				
Age	The actual age of the surveyed farmer (year)	21	76	51.76
Years of education	Education years of the surveyed farmers (year)	0	16	8.36
Years of experience in cultivation	Apple planting years of the surveyed farmers (years)	1	47	23.02
The proportion of agricultural labor	Number of agricultural labors in the family divided by the total number of households	0.2	1	0.74
Total household income	Total household income in 2017 (Ln)	8.91	13.84	10.98
Production characteristics and environmental conditions				
The proportion of irrigated area	The irrigated fruit bearing area divided by the total fruit bearing area of apple	0	1	0.52
Age of apple trees	Average age of apple trees (year)	3.6	37	18.56
Planting density	Number of apple trees cultivated per mu (trees/mu)	20	218.78	47.25
Shaanxi	Dummy variable; 1 = Yes, 0 = No	0	1	0.52
Shandong	Dummy variable; 1 = Yes, 0 = No	0	1	0.32

3.4 Endogenous Discussion

According to the existing literature, the level of informatization in this paper may be endogenous, leading to estimation errors in the empirical analysis. Therefore, to avoid endogenous effects, we use the conditional mixed process (CMP) method proposed by Rodman [39] to estimate the econometric model to avoid endogenous effects. Compared with the traditional 2SLS, the CMP estimation method can better resolve the discontinuity of endogenous variables. The CMP method is also a two-stage estimation process. In the first stage, the instrumental variable of the potential endogenous variable is found and the correlation between the instrumental variable and the endogenous variable is tested; in the second stage, the instrumental variable is substituted into the regression model, and then the value of the parameter atanhrho_12 is used to test the endogeneity of the endogenous variable. If the value of the parameter atanhrho_12 value is significantly different from 0, the model is endogenous and the CMP is effective for estimating the econometric model.

4. Results and Discussion

4.1 The Benchmark Regression

In this paper, "the proportion of 10 households near your home that use the Internet through smartphones" is selected as the instrumental variable of informatization, and the probit model, CMP estimation method are used to estimate model (12), which analyzes whether informatization causes the substitution bias of agricultural machinery inputs for labor inputs in Table 2. The reason why we chose the instrumental variable is that this variable can better reflect the regional informatization level. As the existing literature shows, the degree of information technology diffusion and use in a region has an important impact on the individual informatization level [40]. However, "the proportion of 10 households near your home that use the Internet through smartphones" is relatively exogenous to farmers' choice of labor-saving technology or labor-intensive technology, indicating that the instrumental variable is valid. As for the endogeneity test results, the instrumental variable has a significant positive impact on the informatization at the level of 1% in the first stage, and at the same time, the value of atanhrho_12 is significantly different from 0. This indicates that the variable of informatization level is endogenous, and the instrumental variable and the CMP method are effective. The results and discussion for Table 2 are as follows.

According to the estimation results in Table 3, the level of informatization has a negative significant effect on farmers' choice of labor-saving technology at the 1% level. This result indicates that the level of informatization improves the possibility of selecting labor-intensive technology, and Hypothesis is verified. In terms of the marginal effect, for every 1 unit increase in the level of informatization, the likelihood of selecting labor-intensive technologies increases by 0.224. The possible explanation is that, in apple production, it is much more difficult to find suitable agricultural machinery than labor due to the topographical constraints of the main apple-producing areas. Under this constraint, the level of informatization plays a greater role in reducing the transaction costs of farmers' participation in the labor market than in the machinery market, causing the price ratio of labor and machinery to fall, which induces farmers to choose labor-intensive technologies. It is worth noting that although informatization encourages farmers to choose labor-intensive technology, the reverse induced effect of the level of informatization on labor-saving technology may be short-lived against the background that the labor cost of agricultural production is still rising and the ageing of production units continues to intensify. Therefore, it is very necessary to induce farmers to choose labor-saving technology based on the regulatory role of informatization in the labor and machinery factor markets.

In terms of the impact of price factors on labor-saving technology selection, the apple selling price has a positive and significant impact on farmers' choice of labor-saving technology at the 5% level, which indicates that the increase in apple price will encourage farmers to choose labor-saving technology, contrary to the findings of existing studies. The possible explanation is that the agricultural product market and production factor market are dynamic markets, and the change in agricultural product price will change the input structure of farmers' production factors, which will cause farmers to change the technology selection bias. That is, the effect of agricultural product market price on farmers' choice of labor-saving technology is not stable. The input price ratio of labor and machinery has a positive and significant impact on farmers' choice of labor-saving technology at the 10% level. This result indicates that the higher the price ratio of labor and machinery, the more the farmers tend to choose labor-saving technology. The increasing price ratio of labor and machinery means that the marginal cost of labor input is higher than the marginal cost of machinery input, i.e. labor is more scarce than machinery factor. In this case, farmers tend to increase mechanical inputs to replace labor.

Farmers' risk preference positively affects farmers' choice of labor-saving technology at the 1% level, indicating that farmers with risk preferences prefer labor-saving technology, which is contrary to the existing studies.

The possible explanation is that with the increasing labor costs, farmers with risk preference are more likely to seek alternative labor factors in the factor market and reduce the unit cost of apple production. The distance between the factor market and farmers, and the area of apple production does not have a significant influence on farmers' choice of labor-saving technology.

In terms of household head characteristics, age has a significant negative effect on farmers' choice of labor-saving technology at the 1% level, indicating that older farmers prefer to choose labor-intensive technology. The possible reason for this is that with increasing age, farmers' ideology is easily consolidated and the recognition of labor-saving technology or production mode is low. In comparison, they still stick to the traditional labor mode. In addition, the influence of years of education and farming experience on farmers' choice of labor-saving technology does not pass the significance test. In terms of family characteristics, the proportion of agricultural labor has a significant negative impact on farmers' choice of labor-saving technology at the 1% level, indicating that the households with abundant agricultural labor endowment tend to choose labor-intensive technology. The possible explanation is that the proportion of agricultural labor reflects to some extent the abundance of family labor factors. The more agricultural labor there is in the family, the more farmers tend to increase the input of labor, substituting other relatively scarce factors. Total household income has a positive impact on farmers' choice of labor-saving technology at the 10% level, indicating that the higher the family income, the more likely farmers are to choose labor-saving technology. The possible explanation is that total household income reflects to some extent the degree of capital accumulation of farmers. The higher the total income, the lower the financial constraints on investment in agricultural production, and the more conducive it is to encourage farmers to increase mechanical inputs to replace the relatively scarce factor of labor. In terms of production characteristics, the share of irrigated area, age of apple trees and planting density do not pass the significance test for farmers' choice of labor-saving technology.

In terms of location and environmental conditions, apple farmers in Shaanxi prefer labor-saving technology compared to apple farmers in Gansu province, which may be related to regional differences in apple production mode and labor endowment. Compared with Shaanxi and Shandong, due to the backward economic development in Gansu, the price of agricultural labor is relatively low and labor is more abundant. In addition, the dwarf apple cultivation mode, which is good at "labor saving", is popularized in Shaanxi and Gansu, especially in Shaanxi, which improves the substitution efficiency of mechanical factors for labor factors. It is worth noting that there is no significant difference in technology selection bias between Shandong apple farmers and Gansu apple farmers. The possible explanation is that higher labor prices in Shandong have a pull effect on farmers' choice of labor-saving technology. However, due to the restrictive climatic conditions, it is difficult to popularize the labor-saving production mode in Shandong. The nature of the practical constraints has a push effect on farmers' choice of labor-saving technology, so the two effects may cancel each other out.

4.2 Robustness Test Analysis

In order to further test the robustness of the above research results, this paper takes the technology selection bias index as a proxy variable, and selects "the proportion of 10 households near your home that use the Internet through smartphones" as an instrumental variable. Tobit model and CMP method are used to test the robustness of the impact of informatization level on farmers' choice of labor-saving technology in Table 4. According to the estimation results of the first stage equation, the instrumental variable is correlated with the informatization at the 1% level, and the endogenous test parameter value atanhrho_12 is different from 0 at the 10% level, indicating that the CMP method and instrumental variable selection are effective. The results of the second stage show that the level of informatization has a significant negative impact on the technology selection bias index at the 10% level, which indicates that the increase in informatization will induce farmers to choose labor-intensive technology, which is consistent with the result of the benchmark model. Therefore, the conclusion that the level of informatization negatively affects farmers' choice of labor-saving technology is robust.

4.3 Heterogeneity Analysis

Analysis of Regional Heterogeneity

The above analysis shows that the level of informatization has a significant negative impact on farmers' choice of labor-saving technologies. However, there are obvious regional differences in the level of informatization and the degree of factor market development in different regions, which may lead to the differences in the influence of informatization on farmers' choice of labor-saving technology. Therefore, this paper divides the total sample into two sub-samples according to the geographical region division standard, including the eastern region and the western region. The probit model and CMP method are used to estimate the econometric model in order to test the robustness of the information level affecting farmers' labor-saving technology selection.

Table 2. Results of the benchmark regression.

Variable	Independent variable: labor-saving technology = 1; labor-intensive technology = 0 (CMP-Probit)		
	Stage I Independent variable: Informatization	Stage II	
		Coefficient	Marginal effect
The level of informatization	—	–0.710*** (–2.89)	–0.224*** (–3.26)
Apple selling price	—	0.173** (1.97)	0.055* (1.94)
Input price ratio of the labor-machinery factor	—	0.030* (1.71)	0.009* (1.71)
Distance between factor market and farmers	—	0.001 (0.17)	0.000 (0.17)
Apple farm size	0.011 (1.40)	–0.015 (–0.97)	–0.005 (–0.95)
Farmers' risk preference	0.171*** (5.93)	0.186*** (3.04)	0.059*** (3.28)
Age	–0.035*** (–9.11)	–0.039*** (–3.85)	–0.012*** (–4.37)
Years of education	0.054*** (5.09)	0.026 (1.16)	0.008 (1.19)
Years of experience in cultivation	0.001 (0.29)	–0.008 (–1.05)	–0.003 (–1.04)
The proportion of agricultural labor	–0.110 (–0.92)	–0.531*** (–2.67)	–0.168*** (–2.64)
Total household income	0.159*** (3.54)	0.215* (1.69)	0.068* (1.74)
The proportion of irrigated area	—	0.029 (0.25)	0.009 (0.25)
Age of apple trees	—	0.006 (0.68)	0.002 (0.68)
Planting density	—	–0.000 (–0.04)	–0.000 (–0.04)
Shaanxi	—	0.597*** (3.80)	0.188*** (3.51)
Shandong	—	–0.058 (–0.33)	–0.018 (–0.33)
Constant	0.103 (0.19)	–0.562 (–0.36)	—
IV_1	0.006*** (4.90)	—	—
Atanhrho_12	0.622** (2.19)		
Wald test	654.76***		
Samples	727	727	727

*** p < 0.01, ** p < 0.05, * p < 0.1; Z-value under robust standard error is shown in parentheses; IV_1 is defined as the proportion of 10 households near your home that use the Internet through smartphones.

Table 3. Results of robustness test.

Variable	Independent variable: Technology selection bias index (CMP-Tobit)		
	Stage I Independent variable: Informatization	Stage II	
		Coefficient	Marginal effect
The level of informatization	—	–0.552* (–1.68)	–0.460* (–1.75)
Controlled variables	Controlled	Controlled	Controlled
IV_1	0.006*** (4.90)	—	—
Constant	0.103 (0.19)	1.226 (1.24)	—
Atanhrho_12	0.414* (1.65)		
Wald test	624.44***		
Samples	727	727	727

*** p < 0.01, * p < 0.1; Z-value under robust standard error is shown in parentheses; IV_1 is defined as the proportion of 10 households near your home that use the Internet through smartphones.

According to the results of the subsample fitting in Table 4, in Stage I, the instrumental variables "the proportion of 10 households near your home that use the Internet through smartphones" and "whether the village broadcasts market information or not" are significantly correlated with the level of informatization, and the values of the endogenous test parameter atanhrho_12 are significantly different from 0 at the 1% level, respectively, indicating that the CMP method and instrumental variables are effective. In Stage II, the level of informatization negatively affects the farmers' choice of labor-saving technology in the eastern and western regions, which is consistent with the benchmark regression results, indicating that the negative influence of informatization level on farmers' choice of labor-saving technology is robust at the regional level. However, the impact of the level of informatization level on the choice of labor-saving technology in the eastern region (marginal effect: –0.198) is smaller than that in the western region (marginal effect: –0.303). On the one hand, compared with the eastern region, the informatization process in the western region is lagging behind, and the problem of imperfect and asymmetric information is more serious in the western region, so the marginal effect of the informatization level on the factor market in the western region may be larger. On the other hand, compared with the eastern region, the labor price in the western region is lower, which provides a better environment for inducing farmers to choose labor-intensive technology based on the informatization level.

Table 4. Results of regional heterogeneity analysis.

Variables	Independent variable: labor-saving technology = 1; labor-intensive technology = 0 (CMP-Probit)			
	Eastern region		Western region	
	Stage I	Stage II	Stage I	Stage II
Informatization level	—	–0.686*** (–3.38)	—	–0.999*** (–4.95)
Controlled variables	Controlled	Controlled	Controlled	Controlled
IV_1	—	—	0.005*** (3.09)	—
IV_2	–0.473*** (–2.80)	—	—	—
Constant	–0.005 (–0.00)	—	0.255 (0.41)	0.369 (0.27)
Atanhrho_12	0.727*** (2.61)		1.038*** (2.67)	
Wald test	209.53***		634.98***	
Samples	233	233	494	494

*** $p < 0.01$; Z-value under robust standard error is shown in parentheses; IV_1 is defined as the proportion of 10 households near your home that use the Internet through smartphones; IV-2 is defined as whether the village broadcasts market information or not.

Analysis of Different Dimensions of Informatization

There may be differences in the impact of information technology access level, information technology application level and information literacy level on farmers' information processing efficiency in the three dimensions of informatization, which leads to farmers' heterogeneous transaction cost of participating in the labor and machinery factor market, and further causes the relative price changes of labor and machinery factors, thus causing them to choose heterogeneous labor-saving technology. Based on this, this paper uses the probit model and CMP method to estimate the benchmark model, and discusses the influence of information technology access level, information technology application level and information literacy level on farmers' labor-saving technology choice, so as to further verify the robustness of the above research results.

According to the estimation results in Table 5, the instrumental variable "the proportion of 10 households near your home that use the Internet through smartphones" is significantly correlated with the information technology access level, information technology application level and information literacy level, respectively, and the endogenous test parameter values of anhrho_12 are significantly different from 0 at the 5%, 1% and 5% levels, indicating that the CMP method and instrumental variable are effective. In terms of the results in Stage II, the level of access to information technology, the level of application of information technology and the level of information literacy has a negative effect on farmers' choice of labor-saving technology at the level of 10%, 1% and 1%, respectively, which is consistent with the benchmark estimation results. However, in terms of the marginal effect, the information literacy level has the largest impact on farmers' choice of labor-saving technology (marginal effect: –0.391), followed by the information technology access level (marginal effect: –0.369), and the information technology application level has the smallest effect (marginal effect: –0.078). The level of information literacy reflects the ability of farmers to obtain and process information, which is supposed to eliminate the internal constraints of information asymmetry and directly affects the farmers' decision to participate in the factor market. In contrast, the access to and use of information technology are external constraints that determine the size of the information set available to farmers. Theoretically, the final information for decision making is more dependent on internal constraints, so the marginal effect of information literacy level is larger. In addition, the reason why the marginal effect of information literacy level is smaller than that of information technology access level may be related to the low level of information technology application among farmers, although information technology application is more focused on obtaining factor market information. According to the statistics of the survey data, although 64.79% of the farmers use information technology to obtain information related to agriculture, only 6.46% of the farmers obtain two or more types of information related to agriculture.

Table 5. Analysis results of different dimensions of informatization.

Variables	Independent variable: labor-saving technology = 1; labor-intensive technology = 0 (CMP-Probit)					
	Stage I	Stage II	Stage I	Stage II	Stage I	Stage II
Information technology access	—	–1.108* (–1.87)	—	—	—	—
Information technology application	—	—	—	–0.241*** (–3.15)	—	—
Information literacy	—	—	—	—	—	–1.225*** (–2.60)
Controlled variables	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
IV_1	0.003*** (5.33)	—	0.018*** (4.85)	—	0.003*** (4.76)	—
Constant	0.006 (0.03)	–0.647 (–0.37)	–1.715 (–1.01)	–0.865 (–0.51)	2.080*** (7.88)	1.899 (0.95)
Atanhrho_12	0.386** (2.02)		0.436*** (2.71)		0.586** (2.22)	
Wald test	460.92***		436.48***		417.45***	
Samples	727	727	727	727	727	727

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Z-value under robust standard error is shown in parentheses; IV_1 is defined as the proportion of 10 households near your home that use the Internet through smartphones.

5. Conclusions and Implications

In the context of informatization, the transaction costs of farmers' participation in the factor market may change, leading to a change in the relative prices of factors and inducing farmers to choose the scarce factor-saving technology. However, there is no research to confirm this conclusion. Therefore, this study comprehensively evaluates the informatization level from three aspects of information technology access, information technology application and information literacy, and analyzes the impact of informatization on farmers' choice of labor-saving technology with 727 apple farmers randomly selected. To address endogeneity issues, this paper uses the probit model and CMP method, which can better resolve the discontinuity of endogenous variables compared with the traditional 2SLS.

The empirical results of CMP revealed a negative and significant relationship between informatization and farmers' choice of labor-saving technology, and the conclusion is robust at the regional level, but the negative impact of the level of informatization on farmers' choice of labor-saving technology is smaller in the eastern region than that in the western region. The effects of three different dimensions of informatization on farmers' choice of labor-saving technology are varied. In particular, the level of information literacy has the largest impact on farmers' choice of labor-saving technology, followed by the level of access to information technology, and the level of information technology application is the least. Furthermore, some factors were identified as important drivers of farmers' choice of labor-saving technology. Especially, the apple selling price, farmers' risk preference, total household income, labor-machinery factor input price ratio had a positive and significant impact on farmers' choice of labor-saving technology, while age, the proportion of agricultural labor had a significant negative effect on farmers' choice of labor-saving technology. However, Several factors did not impact significantly farmers' choice of labor-saving technology, including the distance between factor market and farmers, apple farm size, years of education, years of experience in cultivation, the proportion of irrigated area, age of apple trees and planting density.

Based on the above conclusions, this paper has two implications:

(1) The government should seize the opportunity of rural revitalization and development to coordinate the popularization of information technology and the improvement of information literacy, formulate differentiated regional informatization development strategies, orderly promote agricultural and rural informatization, comprehensively improve the informatization level of farmers, invigorate the factor market and effectively reduce the transaction cost of farmers' participation in the factor market. First, we should join hands with network operators to lower the tariff standards of mobile Internet and fixed broadband Internet to improve the information access level in rural areas. Second, we should promote factor market innovation based on big data or cloud computing, and guide farmers to use information technology to obtain market informa-

tion and production factors. Third, we should promote information training in various ways (e.g. adult education and on-site guidance training) to gradually improve farmers' information literacy.

(2) The government should strengthen the innovation of mechanical technology suitable for the current apple cultivation mode, and pay attention to the construction of an information disclosure mechanism for the agricultural machinery market or mechanized service market based on information technology, so as to reduce the transaction cost of farmers' participation in agricultural machinery market and mechanized service market, and guide farmers to choose labor-saving technology, so as to avoid farmers to fall into the trap of technological progress.

Overall, this paper examines the impact of informatization on the relative input bias of machinery and labor factors by taking apple farmers as an example, providing a Chinese case for the application of induced technological change theory in the context of informatization. However, due to the relatively slow technological progress of machinery and the upgrading of agricultural machinery in the apple production process, it may lead to relatively high fixed transaction costs for farmers to participate in the machinery factor market. However, this issue is not well addressed in the analysis of this paper due to measurement difficulties, which may affect the input costs of machinery factors for farmers and thus lead to changes in the relative input bias of mechanical labor. This is a research deficiency of this paper and we hope to be able to identify this problem more precisely in further research.

Author Contributions

Congying Zhang collected all field data, analyzed, interpreted the result, and wrote the manuscript. Jingru Xiang analyzed, interpreted the result, and wrote the manuscript. Qian Chang interpreted the result and reviewed the paper.

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Data Availability

Data used for this study are extracted from the Rural Micro Survey and can be accessed from the corresponding author upon request.

Conflict of Interest

All authors disclosed no conflict of interest.

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