jotaf **Journal of Tekirdag Agricultural Faculty**
Tekirdağ Ziraat Fakültesi Dergisi

Ekim/October 2025, 22(4)
Başvuru/Received: 04/09/24
Kabul/Accepted: 01/05/25
DOI: 10.33462/jotaf.1540354

http://dergipark.gov.tr/jotaf
http://jotaf.nku.edu.tr/

ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Spillover Effect of Human Capital and Human Development in Shaping Agricultural Productivity—Scope of Indonesian Capital City (IKN)*

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Abstract

Penajam Paser Utara (PPU) is recognized as a region rich in natural resources, with agriculture serving as its primary sector. Concurrently, the Indonesian government has relocated the administrative center from Jakarta to PPU. Given that PPU is situated in the center of Indonesia, the primary rationale for moving the Indonesian Capital City (IKN) is to equalize infrastructure and integrate the economy across all regional levels. In addition to undertaking complex developmental improvements, PPU faces new challenges in maintaining its existing agricultural prospects while transitioning into a comprehensive IKN development zone. Despite overlapping economic policies, PPU must implement concrete strategies to establish itself as a significant agricultural commodity-producing region for East Kalimantan, particularly for IKN. This study aims to explore the relationship between investment, labor, Information and Communication Technology (ICT), and the Farmer's Exchange Rate (NTP) on agricultural productivity, irrespective of the involvement of human capital and human development. The dataset covers the period from 2015 to 2023 and is processed using Moderated Regression Analysis (MRA). The objectivity of the study is on PPU as an IKN. Empirical evidence indicates that ICT has a significant impact on human development (p < 1%). Both labor and ICT significantly influence agricultural productivity (p < 5%). Furthermore, while human capital was unable to serve as a moderating variable, human development significantly moderated the relationship between labor and agricultural productivity (p < 5%). The novelty of this study lies in identifying a gap not addressed by previous research, thereby contributing to the advancement of fresher thinking in the formulation of agricultural productivity models. The study's findings offer practical recommendations for the government to enhance agricultural productivity through the support of intensive investment programs. By implementing effective investment policies, it is anticipated that technological advancements will be revitalized. The adoption of technology is essential for developing human capital and fostering human development, which, in turn, shapes labor skills and promotes prosperity in the agricultural sector.

Keywords: Human capital, Human development, Agricultural productivity, MRA, IKN

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Atıf/Citation: Junaidi, A., Busari, A., Kurniawan A., E., Gani, I., Darma, D. C. (2025). Spillover effect of human capital and human development in shaping agricultural productivity—scope of Indonesian Capital City (IKN). *Journal of Tekirdag Agricultural Faculty,* 22(4): 942-955.

*This study is summarized from the grant research report of the Faculty of Economics and Business at Universitas Mulawarman number 2372/UN17/HK.02.03/2024.
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1. Introduction

Darma et al. (2022) and Steensland and Zeigler (2021) define agricultural productivity as the capacity of land to yield specific crops, measured as the ratio of output to input. Agricultural productivity can also be assessed based on land area, particularly in plantations. Specifically, it refers to the carrying capacity and efficiency of agricultural land in producing crops (Sukri et al., 2023). Productive land is characterized as land capable of generating substantial crop yields, which benefits agricultural managers. Agricultural productivity reflects the balance between expected harvest outcomes and the costs or area of land utilized (Adriansyah et al., 2023). In an economic context, agricultural productivity indicates the volume of output that can be generated from a given set of inputs. In this regard, productivity in the agricultural sector signifies a sustained increase in output relative to production inputs (Rosyadi et al., 2023). Basically, agricultural productivity is a key component of prosperity for countries and regions that rely on their natural resources within the agricultural sector. It plays a crucial indicator of sustainable development in this sector. Furthermore, the agricultural sector acts as a driving force for the growth of other sectors, aligned with potential and economic conditions (Fitriadi et al., 2024). Substantially, one of the primary parameters for success in agricultural productivity is agricultural economic performance, as reflected in Gross Domestic Product (GDP). Jiuhardi et al. (2022) state that agricultural GDP represents the accumulation of revenue generated from the management of biological resources within the framework of domestic. This sector is categorized into five sub-sectors: (1) food crops, (2) plantations, (3) animal husbandry, (4) forestry, and (5) fisheries. Excellence in the agricultural sector is visualized by the production volume generated by both workers and farmers over a specific period. In the case of an agrarian country like Indonesia, the agricultural sector has served as the backbone of the economy for the past century (Kurniawan et al., 2024; Rosyadi and Wijaya, 2024). The agricultural sector in Indonesia plays a vital role in fostering socio-economic prosperity by creating opportunities and absorbing a substantial workforce.

Recently, Indonesia has encountered big challenges in achieving equitable economic development, especially advancing the agricultural sector inclusively. One of the efforts to reduce disparities within this sector involves relocating the Indonesian Capital City (IKN) from Jakarta to East Kalimantan (Nurjanana et al., 2025). This relocation aims to ensure that regions such as Java and Sulawesi, which serve as agricultural hubs, continue to focus on producing high-quality agricultural commodities (Jiuhardi et al., 2024). The IKN relocation process began in 2022 and is ongoing, as mandated by Law Number 3 of 2022 of the Republic of Indonesia. The target for the completion of IKN is projected for the end of 2024, with a primary emphasis on relocating the administrative center. According to these regulations, IKN is located in Sepaku. Initially, Sepaku was a sub-district of Penajam Paser Utara (PPU), but it has since evolved into a strategic location for the IKN authority, which operates independently from the East Kalimantan Provincial government. Although the Sepaku area has been expanded and is no longer part of PPU, PPU remains committed to supporting the needs of IKN, particularly in terms of food security. Talking about food security, the spillover effects from the agricultural sector in PPU Regency have significantly contributed to the economic growth of East Kalimantan. Over the past five years (2019–2023), data from BPS-Statistics of East Kalimantan Province (2024) reports that the agricultural sector's average contribution to the Gross Regional Domestic Product (GRDP) was 8.06%, with the highest contribution recorded in 2021 at 8.49%. Additionally, the IKN scenario continues to position PPU as a buffer zone that can enhance food security.

In the microeconomic corridor, Bala and Shuaibu (2024), Farrokhi and Pellegrina (2023), Firdaus et al. (2024), Kastratović (2023), and Zhang and Sun (2023) identify four factors of production that influence agricultural GDP: (1) capital, (2) labor, (3) technology, and (4) exports. This study highlights the Farmer Exchange Rate (NTP) to evaluate the capacity of products produced by farmers in relation to the inputs required for production and household consumption. In agriculture, capital refers to the wealth utilized to directly or indirectly facilitate the production process. It can take various forms, including money, equipment, land, seeds, and fertilizers. Capital is essential in agriculture due to its role in providing land, covering operational costs for cultivation, and facilitating the distribution of agricultural commodities, among other functions. In practice, farmers acquire capital from both their own resources and borrowed funds. Their own capital typically derives from income and savings, while borrowed capital can be obtained from financial institutions, non-bank loans, and intermediaries.

Exports can be associated with NTP. In principle, NTP refers to the increased output of agricultural commodities achieved through processing, transportation, or storage (Priyagus et al., 2024). The added value can be enhanced by incorporating ingredients that make the commodity more appealing to buyers or easier for consumers to use. NTP per worker is estimated by dividing the total economic value generated from the five agricultural sub-sectors by the number of farmers and farm laborers employed in these sectors, adjusted for inflation; however, it does not account for variations in the cost of living across different countries. Increasing the capacity of agricultural products can contribute to achieving food security for farming households. Food security is a fundamental concept that must be realized to ensure the basic needs of all segments of society are met. One of the indicators of whether agricultural productivity is functioning optimally is the export intensity of specific agricultural commodities. In other words, NTP also serves as a signal of farmer prosperity, encouraging trade in agricultural commodities.

The four production factors mentioned above are considered insufficient to stimulate agricultural productivity. While these existing factors are currently key elements influencing agricultural productivity, they remain limited in their endogenous capacity. For this reason, it is essential to consider additional components beyond the existing factors, for example human capital and human development (Sarı Gedik and Yılmaz, 2023). By incorporating these two components, agricultural productivity can grow optimally. It is well established that human capital and human development are interrelated attributes. From a macroeconomic perspective, these attributes can determine the future of the economy, including the agricultural sector (Miranti et al., 2024; Rao, 1996). Apart from being subjects, humans also objects of agricultural development. To become well-rounded individuals, access to health and education is essential for successfully entering the agricultural job market (Nechar et al., 2021). With adequate standards in health and education, workers can enhance their well-being. In turn, improved welfare opens up insights into understanding and elevating the quality for individuals and households, thereby facilitating better access to education and healthcare. In the agricultural industry, empowerment extends beyond just farmers; it also aims to foster prosperity on a broader scale, recognizing that the population plays a vital role in this process.

Schultz (1981) developed the concept of human capital within the scope of U.S. farmers. By adopting more efficient practices, farmers can increase production while utilizing less capital, labor, and land. Furthermore, physical capital generates lower profits compared to human capital. Nkandu and Phiri (2022) examined the impact of ICT on agricultural productivity in the Southern Province of Zambia. The Unified Theory of Acceptance and Use of Technology (UTAUT) was employed to highlight the socio-economic aspects that influence ICT adoption. Behavioral intentions regarding ICT adoption are shaped by performance expectancy, social influence, effort expectancy, and facilitating conditions. The analysis concluded that agricultural productivity is significantly influenced by ICT adoption. Huang and Wang (2024) and Zhu et al. (2024) observed that socio-economic development substantially improves labor productivity among farmers in China. However, rapid socio-economic progress has not sufficiently addressed the regional disparities in the agricultural productivity. To ensure the long-term sustainability of agricultural growth, it is essential to adopt a balanced and integrated approach to socio-economic development that incorporates environmental considerations and new technologies. Human development within a nation is intrinsically linked to education, which serves as a powerful tool for alleviating poverty. Kabiru (2020) linked the relationship between education and agricultural productivity, emphasizing the moderating role of self-help institutions in Katsina State, Nigeria. There is a positive correlation between education and agricultural productivity, with self-help institutions significantly influencing this relationship.

The urgency of this study is to elucidate the causal relationships between production factors in agriculture, specifically: (1) investment, (2) labor, (3) ICT, and (4) NTP on agricultural productivity, both with and without the influence of human capital and human development. To the authors' knowledge, there are still few manuscripts that address the aforementioned four production factors in relation to agricultural productivity in developing markets. Then, there is currently no publication that incorporates human capital and human development as bridging in the relationship between production factors (investment, labor, ICT, and NTP) on agricultural productivity. By including these two moderating factors, this study aims to provide both theoretical preferences and practical implications for sustainable agricultural models. Another originality lies in its focus on the IKN area, which has been deliberately selected for evaluation in the matter of policy-making in the agricultural sector.

2. Materials and Methods

2.1. Approach and Data Collection

This study was designed using an associative approach to identify the benefits of quantitative data. Quantitative data were collected from the BPS-Statistics of North Penajam Paser over nine periods (2015–2023). The data collection techniques involved selection, recording, compilation, and documentation. Technically, these data pertain to various studies, including: (1) investment, (2) labor, (3) Information and Communication Technology/ICT, (4) Farmer's Exchange Rate/NTP, (5) the Human Capital Index/HCI, (6) the Human Development Index/HDI, and (7) the Gross Regional Domestic Product/GRDP of the agricultural sector.

2.2. Variable Model

The variable model is structured around two schemes: direct relationships and indirect relationships, which are further divided into six distinct paths. First, it examines the link between investment, labor, ICT, and NTP on human capital. Second, this study examines the link between investment, labor, ICT, and NTP in relation to human development. Third, it explores the link between human capital and human development as it pertains to agricultural productivity. Fourth, the study investigates link between investment, labor, ICT, and NTP concerning agricultural productivity. Fifth, it analyzes how the link between investment, labor, ICT, and NTP on agricultural productivity is moderated by human capital. Sixth, the study considers how the link between investment, labor, ICT, and NTP on agricultural productivity is moderated by human development. *Table 1* below summarizes the operational definitions of each variable.

Table 1. Variable details

Variable type	Sub-variables	Coding (unit)	Measurements
Independent	Investment	Inv (Rupiah/IDR)	Value of loans to banks in the agricultural sector
	Labor	Lbr (%)	Percentage of the population aged 15 years and older who work in the agricultural sector
	Information and communication technology	ICT (towers/stations)	A series of electronically connected and installed telecommunications devices
	Farmer's exchange rate	NTP (score)	Comparison of the Price Index Received by farmers and the Price Index Paid by farmers
Moderating	Human capital	HC (index)	Comparative indicators of human development quality in a country based on aspects of life expectancy, educational aspects such as years of schooling and average years of schooling, and living standards measured by purchasing power parity (PPP)
	Human development	HD (index)	An international metric that serves as a benchmark for human development by incorporating education and health components to promote future
Dependent	Agricultural productivity	AP (%)	The growth of Gross Regional Domestic Product (GRDP) in the agricultural sector is described based on constant prices from the 2010 series

Source: BPS-Statistics of Penajam Paser Utara (2024).

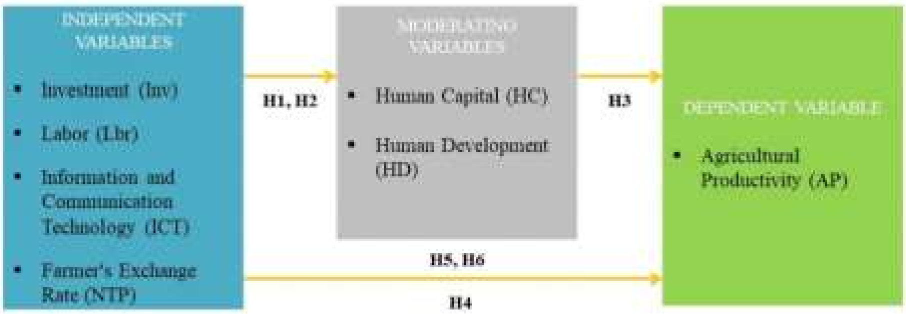

Figure 1. Conceptual framework

There are three types of variables utilized in this study. First, the independent variables include investment, labor, ICT, and NTP. Second, the moderating variables are represented by human capital and human development. Third, the dependent variable is agricultural productivity. Consequently, six hypotheses were developed within the conceptual framework, as illustrated in *Figure 1*. To address the study objectives, the hypotheses were formulated as follows:

- Null hypothesis (H_0): It is assumed that both direct and indirect relationships negatively influence investment, labor, ICT, and NTP on human capital, human development, and agricultural productivity.
- Alternative hypothesis (H_a): It is assumed that both direct and indirect relationships positively influence investment, labor, ICT, and NTP on human capital, human development, and agricultural productivity.

2.3. Analysis Tools

Quantitative data in the form of time series were extracted using Moderated Regression Analysis (MRA). In addition to predicting direct relationships, the MRA method is also employed to forecast indirect relationships between variables. Similar to linear and multiple regression, the three systematics of MRA include presenting data characteristics through descriptive statistics, tabulating the strength of correlation, and testing hypotheses. MRA was constructively adopted and modified from previous scientific research on topics related to sustainable agricultural productivity (*e.g.*, Ansah et al., 2023; Barkah et al., 2022; Febriyanti et al., 2022; Kabiru, 2020; Li et al., 2019; Sarwoto, 2018). The statistical software used to validate the data is SPSS version 29. The econometric equations for direct and indirect relationships are expressed as follows:

$$\gamma_1 = \alpha_0 + \Delta ln\beta X_1 + \Delta ln\beta X_2 + \Delta ln\beta X_3 + \Delta ln\beta X_4 + \varepsilon_{it} \quad \text{(Eq. 1).}$$

$$\gamma_2 = \alpha_0 + \Delta ln\beta X_1 + \Delta ln\beta X_2 + \Delta ln\beta X_3 + \Delta ln\beta X_4 + \varepsilon_{it} \quad \text{(Eq. 2).}$$

$$\gamma_3 = \alpha_0 + \Delta\beta X_5 + \Delta\beta X_6 + \varepsilon_{it} \quad \text{(Eq. 3).}$$

$$\gamma_3 = \alpha_0 + \Delta ln\beta X_1 + \Delta ln\beta X_2 + \Delta ln\beta X_3 + \Delta ln\beta X_4 + \varepsilon_{it} \quad \text{(Eq. 4).}$$

$$\gamma_3 = \alpha_0 + \Delta ln\beta X_1 + \Delta ln\beta X_5 + (\Delta ln\beta X_1.\Delta\beta X_5) + \Delta ln\beta X_2 + \Delta ln\beta X_5 + (\Delta ln\beta X_2.\Delta\beta X_5) + \Delta ln\beta X_3 + \Delta ln\beta X_5 + (\Delta ln\beta X_3.\Delta\beta X_5) + \Delta ln\beta X_4 + \Delta ln\beta X_5 + (\Delta ln\beta X_4.\Delta\beta X_5) + \varepsilon_{it} \quad \text{(Eq. 5).}$$

$$\gamma_3 = \alpha_0 + \Delta ln\beta X_1 + \Delta ln\beta X_6 + (\Delta ln\beta X_1.\Delta\beta X_6) + \Delta ln\beta X_2 + \Delta ln\beta X_6 + (\Delta ln\beta X_2.\Delta\beta X_6) + \Delta ln\beta X_3 + \Delta ln\beta X_6 + (\Delta ln\beta X_3.\Delta\beta X_6) + \Delta ln\beta X_4 + \Delta ln\beta X_6 + (\Delta ln\beta X_4.\Delta\beta X_6) + \varepsilon_{it} \quad \text{(Eq. 6).}$$

where; γ_1 = human capital, γ_2 = human development, γ_3 = agricultural productivity, α_0 = constant or intercept, Δln = logarithmic slope, β = regression coefficient, X_1 = investment, X_2 = labor, X_3 = ICT, X_4 = NTP, X_5 = human capital, X_6 = human development, and ε_{it} = error in time-series.

Basically, MRA is an advanced form of regression that involves the interaction between predictor variables and moderator variables (Azis et al., 2024). In other words, MRA is employed to justify whether the relationship between the independent variable (predictor) and the dependent variable (response) is influenced by another variable known as the moderator. Seven main advantages of MRA, as outlined by Daryanto (2019), Hair et al. (2021), and Helm and Mark (2012), are as follows: (1) its capacity to test interaction effects between variables, (2) its ability to capture complexity and enriches social research, (3) greater flexibility in hypothesis testing, (4) improved predictive capability, (5) assistance in overcoming data variability, (6) representation of external conditions or contextual factors that improve external validity, and (7) identification of significant moderator variables.

3. Results and Discussion

3.1. Findings

The three instruments utilized in MRA are descriptive statistics, correlation tests, and hypothesis tests. First, descriptive statistics provide an overview of the data used in the study, including the mean, standard deviation (SD), maximum, and minimum values. Generally, because the data categories examined have different units, the values vary accordingly. Based on the descriptive statistics, the minimum investment value is IDR 6.663.874.694, while the maximum value reaches IDR 2.391.039.385.038. The mean investment value is IDR 849.211.780.963, with an SD of IDR 1.045.402.506.532. Over a period of nine years, the minimum percentage of the workforce was 38.48%, while the maximum percentage was 48.85%, and the mean percentage was 43.61%, with an SD of 4.34%.

As shown in *Table 2*, data diversity is also evident in other variables, such as ICT, NTP, human development, human capital, and agricultural productivity. In the ICT variable, the minimum number of installed towers/stations was 86 units, while the maximum was 144 units. Meanwhile, the average number of tower/station installations in IKN reached 123 units per year, with a SD of 21.87 units during the observation period.

Table 2. Descriptive statistical matrix

	Minimum	Maximum	Mean	SD	Obs.
Inv	6.663.874.694	2.391.039.385.038	849.211.780.963	1.045.402.506.532	9
Lbr	38.48	48.85	43.61	4.34	9
ICT	86	144	123	21.87	9
NTP	96.27	125.95	107.4	12.95	9
HD	69.26	73.3	71.32	1.26	9
HC	.53	.68	.59	.07	9
AP	–2.5	3.14	.36	1.46	9

Source: Data recapitulation with SPSS.

In the fourth variable (NTP), the minimum value is 96.27 points, while the maximum value reaches 125.95 points. The mean value is 107.4 points, and the SD is 12.95 points. For the HD variable, the minimum value is 69.26 points, with an SD of 1.26 points. The maximum score is 73.3 points, and the mean score is 71.32 points. *Table 2* also indicates that the minimum value for HC is 0.53 points, the maximum value is 0.68 points, the mean value is 0.59 points, and the SD is 0.07. Notably, there are significant variations in agricultural productivity, with a minimum value of –2.5%. Uniquely, the mean and SD values for agricultural productivity are 0.36% and 1.46%, respectively, while the maximum value reaches 3.14%.

Second, correlation testing is employed to evaluate the feasibility of a model in two directions. There are two interpretations of the correlation test. If the correlation coefficient is negative (–) and close to or less than 0, the regression model is classified as weak. With probability levels below 1% ($p < 0.01$) or 5% ($p < 0.05$), it was found that while labor and human capital are positively correlated with agricultural productivity, the other four variables—investment, ICT, NTP, and human development—exhibit a negative correlation with agricultural productivity, and vice versa.

Table 3. Summary of correlation

	Inv	Lbr	ICT	NTP	HD	HC	AP
Inv	1	–.349	.802**	.408	.667*	–.650	–.016
		(.357)	(.009)	(.276)	(.050)	(.058)	(.967)
Lbr	–.349	1	–.706*	–.906**	–.796*	.553	.514
	(.357)		(.033)	(.001)	(.010)	(.123)	(.157)
ICT	.802**	–.706*	1	.738*	.964**	–.630	–.017
	(.009)	(.033)		(.023)	(.000)	(.069)	(.966)
NTP	.408	–.906**	.738*	1	.839**	–.551	–.301
	(.276)	(.001)	(.023)		(.005)	(.124)	(.432)
HD	.667*	–.796*	.964**	.839**	1	–.567	–.028
	(.050)	(.010)	(.000)	(.005)		(.111)	(.942)
HC	–.650	.553	–.630	–.551	–.567	1	.452
	(.058)	(.123)	(.069)	(.124)	(.111)		(.222)
AP	–.016	.514	–.017	–.301	–.028	.452	1
	(.967)	(.157)	(.966)	(.432)	(.942)	(.222)	
Obs.	9	9	9	9	9	9	9

Source: Data recapitulation with SPSS.
Note: *$p < 0.05$ and **$p < 0.01$.

Table 3 demonstrates that at a probability level below 1% ($p < 0.01$), there is a positive correlation between investment and ICT ($R = 0.802$; $p = 0.009$), a negative correlation between NTP and labor ($R = –0.906$; $p = 0.001$), a positive correlation between human development and ICT ($R = 0.964$; $p = 0.000$), and a positive correlation between human development and NTP ($R = 0.839$; $p = 0.005$). At a probability degree below 5% ($p < 0.05$), additional findings indicate a positive correlation between human development and investment ($R = 0.667$; $p = 0.050$), a negative correlation between ICT and workforce development ($R = –0.706$; $p = 0.033$), a negative correlation between human development and labor (R = –0.796; p = 0.010), and a positive correlation between NTP and ICT (R = 0.738; p = 0.023).

Third, the mechanism of hypothesis testing is designed to verify the causality of both direct and indirect relationships through MRA. Each hypothesis test encompasses constant, partial, and simultaneous effects. Hypothesis testing also evaluates the accuracy of the model, represented by the coefficient of determination (R^2), which ranges from 0 to 1. Implicitly, the five intervals in the R^2 measure are as follows: (1) very low = 0 to 0.199, (2) low = 0.2 to 0.399, (3) moderate = 0.4 to 0.599, (4) strong = 0.6 to 0.799, and (5) very strong = 0.8 to 1. The constant effect indicates a value that remains independent of all the variables included in the linear model. There are two postulates regarding constant values: negative constants arise when the data range is significantly dispersed, while positive constants occur when the data range is relatively compact. Model 1 indicates that the constant value of the relationship between investment, labor, ICT, and NTP is negative (α_1 = –16.184). This finding is consistent for both partial and simultaneous relationships, as none of the independent variables significantly affect human capital. However, a moderate model fit was observed for the factors influencing human capital (R^2 = 0.592; p = 0.585). In contrast, model 2 is characterized by a positive linear relationship (α_2 = 3.759). With a probability level below 1% (p < 0.01), ICT has a partial influence on human development (p = 0.009), while investment, labor, ICT, and NTP collectively influence human development simultaneously (p = 0.002). The coefficient of determination (R^2 = 0.975; p = 0.002) shows that human development is significantly influenced by investment, labor, ICT, and NTP, demonstrating a very strong model fit.

Table 4. Regression without moderation and with moderation

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant	–16.184	3.759**	–141.780	–168.734	–7.795	–133.619
	(.665)	(.000)	(.435)	(.074)	(.362)	(.087)
Inv	–.012	–.001		–.467	.013	–.098
	(.587)	(.275)		(.183)	(.987)	(.229)
Lbr	.260	.004		25.504*	4.251	5.424*
	(.671)	(.906)		(.041)	(.448)	(.033)
ICT	–.227	.081**		11.370*	9.153	2.029
	(.791)	(.009)		(.027)	(.484)	(.176)
NTP	–.177	.030		6.521	–9.964	.804
	(.768)	(.331)		(.463)	(.433)	(.667)
HC			15.469			
			(.177)			
HD			31.158			
			(.454)			
R^2	.592	.975	.282	.735	.499	.716
F (prob.)	.870	38.494**	1.175	2.775*	.994	2.517*
	(.585)	(.002)	(.371)	(.013)	(.502)	(.046)
Obs.	9	9	9	9	9	9

Source: Data recapitulation with SPSS.
Note: *p < 0.05 and **p < 0.01.
Specifications: Model 1 (HC formed by Inv, Lbr, ICT, and NTP); Model 2 (HD formed by Inv, Lbr, ICT, and NTP); Model 3 (AP formed by HC and HD); Model 4 (AP formed by Inv, Lbr, ICT, and NTP); Model 5 (AP formed by Inv, Lbr, ICT, and NTP through HC); and Model 6 (AP formed by Inv, Lbr, ICT, and NTP through HD).

Similar to model 1, model 3 also exhibits a negative constant value (α_3 = –141.780). Both variables—human capital and human development—do not significantly affect agricultural productivity, either partially or simultaneously. The coefficient of determination (R^2 = 0.282; p = 0.371) implies that the existing model is classified as having low explanatory power. As shown in *Table 4*, despite a negative constant (α_4 = –168.734), the partial regression in model 4 reveals a significant influence of labor (p = 0.041) and ICT (p = 0.027) on agricultural productivity. Then, investment, labor, ICT, and NTP collectively have a significant impact on agricultural productivity (p = 0.013). These four variables also explain model 4 with a strong degree of explanatory power (R^2 = 0.735; p = 0.013).

Both model 5 and model 6 exhibit negative constant values (α_5 = –7.795; α_6 = –133.619). Yet, there are notable differences between the two, particularly concerning the moderating relationship, simultaneous relationship, and model strength. In model 5, none of the independent variables significantly impact agricultural productivity through human capital. Aside from the indirect effects, the simultaneous effects indicate that investment, labor, ICT, and NTP, when moderated by human capital, have an insignificant impact on agricultural productivity. The influence of human capital results in a model of agricultural productivity characterized by moderate models (R^2 = 0.499; *p* = 0.502). In contrast, model 6 reveals a significant moderating relationship, where labor, when moderated by human development, has an indirect effect on agricultural productivity (*p* = 0.033). At a probability level below 5% ($p < 0.05$), it can be concluded that investment, labor, ICT, and NTP significantly influence agricultural productivity through human development simultaneously (*p* = 0.046). With the influence of human development, these four independent variables also create a moderately strong model for agricultural productivity (R^2 = 0.716; *p* = 0.046).

Ideally, both *R* and R^2 should exhibit high coefficients and be statistically significant to be considered reliable for decision-making or further interpretation. Although both values are elevated, this does not necessarily guarantee that the detected relationship is statistically significant. In addition to the possibility of coincidence or other external influences not accounted for in the analysis, factors such as variability, noise, and overfitting must also be considered (Greenland et al., 2016; Subramanian and Simon, 2013). First, variability and noise. Data that contains substantial variability and noise often yields correlation or determination coefficients that appear high, yet their influence may not be strong enough to be deemed significant. Second, overfitting. In highly complex models, both *R* and R^2 can be elevated due to the model's tendency to overfit the sample data, which limits its generalizability to a larger population.

3.2. Discussion

As is well known, none of the hypotheses are accepted in model 1. Neither investment, labor, ICT, or NTP have a significant effect on human capital. Investment, labor, ICT, and NTP are unable to enhance human capital in the IKN for the contemporary term. The relationship between investment and human capital has been reviewed by Alawamleh et al. (2019), Hendarmin and Kartika (2019), and Saroj et al. (2024). According to human capital theory, investment stimulates increased competence through training and education, enabling individuals to seize opportunities for success. Moreover, with the effective utilization of human resources, these can become personal attributes and knowledge that benefit one's career (Gul et al., 2022). Skilled labor encompasses both physical and mental efforts to deliver services efficiently (Sani et al., 2018). In this situation, organizations can achieve profitability by maintaining a reliable workforce, which is regarded as a long-term asset. Apart from education and training, the quality of human capital is also influenced by learning media. For this reason, the use of ICT is not a novel concept amidst this rapid advancement in civilization. ICT plays a crucial role in the development of human resource capital (Qamruzzaman and Karim, 2020). When managed comprehensively, ICT can transform the economy (Ejemeyovwi et al., 2018; Haini, 2021; Samoilenko and Ngwenyama, 2011). According to the conditions in the agricultural sector, fluctuations in NTP will create uncertainty regarding the overall economy, including human capital. Universally, the Indonesian population is heavily reliant on the agricultural sector for their livelihoods (Elfira et al., 2022). Disruptions in this sector, particularly those affecting exports, will undoubtedly impact farmers. For instance, a compromised agricultural supply chain can lead to inflation (Yasin and Amin, 2021). Consequently, agricultural commodity networks may struggle to distribute products normally, resulting in a drastic increase in food prices (Syekh, 2020). In such a scenario, the population faces challenges in accessing adequate health, nutrition, and essential substances that meet the body's needs. As a result, physical health may not be maintained at optimal levels, as proper food intake is crucial for sustaining human capital (Darma et al., 2020).

In model 2, ICT has a significant impact on human development. Conversely, investment, labor, and NTP have an insignificant effect on human development. Only ICT is capable of enhancing human development in the context of the IKN, thereby supporting one hypothesis in model 2. In analyses related to the agricultural sector, both investment and labor, along with NTP, demonstrate a significant connection with human development (Dwiputri et al., 2023; Maharani et al., 2023; Nasution et al., 2021; Qorri et al., 2024; Yekimov et al., 2023).

In model 3, neither human capital nor human development significantly affects agricultural productivity; therefore, neither hypothesis is accepted. Ironically, human capital and human development do not enhance agricultural productivity in the short term. Several studies indicate that human capital and human development positively interact with agricultural productivity (Busari et al., 2025). Improvements in physical institutions, such as human resources, can influence agricultural productivity. The majority of low-income countries experience food insecurity due to low agricultural productivity (Ndour, 2017). Agricultural productivity is highly dependent on human capital. Consequently, it is essential to have human resources complemented by skilled education, training, and experience to support the agricultural sector (Bashir et al., 2018).

The evaluation results prove that two variables—labor and ICT—exhibit a significant relationship with agricultural productivity, whereas investment and NTP have an insignificant effect on agricultural productivity. The two hypotheses in model 4 can be accepted, indicating that labor and ICT can enhance agricultural productivity in the IKN in the short term. Blanco and Raurich (2022), Lio and Liu (2006) and Nkandu and Phiri (2022) found a synergistic relationship between labor and ICT concerning agricultural productivity. Other literature indicates that investment and NTP can significantly boost agricultural productivity (Djokoto et al., 2024; Petre and Ion, 2019; Setiyowati et al., 2018). The connection between NTP and agricultural productivity is evidenced by the fact that as agricultural productivity increases, the costs incurred by farmers for purchasing agricultural production inputs tend to decrease. This reduction can lead to a lower price index for farmers, thereby increasing their income and enabling them to achieve a more adequate level of prosperity. NTP is largely influenced by farmers' income from agricultural outputs, as well as their expenditures on food and non-food items.

Tests involving human capital as a moderating variable in model 5 indicate that investment, labor, ICT, and NTP do not significantly affect agricultural productivity. None of the hypotheses are accepted in model 5, suggesting that the four independent variables fail to enhance agricultural productivity through human capital in the context of the IKN for the contemporary term. Djomo and Sikod (2012) and Setyadi et al. (2020) have demonstrated that investments in health and education are critical factors in the relationship between human resources and economic productivity, with experience also serving as a key determinant of human capital that influences agricultural productivity, particularly farmer income. Regarding the relationship between ICT and agricultural productivity through human capital, Azam et al. (2023), Rajkhowa and Baumüller (2024) and Wang et al. (2024) assert that ICT has potential and serves as an important channel for enhancing the productivity of agricultural workers. The contributions of ICT and human resources are crucial for enhancing agricultural productivity in a diverse manner. Moreover, the emergence of the digital economy in developing markets has significantly altered agricultural production patterns. This digital economy, supported by improved human resources, has a profound impact on agricultural productivity. However, NTP may not necessarily influence agricultural productivity as measured by farmers' income levels (Rai, 2021). From the perspective of the NTP, the development of human capital is essential for addressing issues related to farmer welfare.

Finally, while investment, ICT, and moderated NTP have an insignificant impact on agricultural productivity, labor has a significant effect on agricultural productivity through human development. Thus, one proposed hypothesis has been accepted in model 6. Essentially, labor drives agricultural productivity through human development in the IKN for the contemporary term. In contrast to the other three variables (investment, ICT, and NTP), labor, when supported by human development, contributes significantly and positively to agricultural productivity. Increasing agricultural productivity also plays a vital role in structural change, enhancing the quality of human labor and accelerating human development (Grabowski and Self, 2022). Real food prices, along with the rise in per capita food demand, significantly influence the sustainability of agricultural productivity. Unstable growth in agricultural productivity can lead to fluctuations in labor dynamics, potentially disrupting crop yields. According to Dorward (2013) and Emran and Shilpi (2018), a shift in demand for labor in the agricultural sector—from positive to negative—will result in a reduction in labor supply, a decrease in wages, an increase in the poverty gap, and even impact the agricultural commodity market itself.

4. Conclusions

The synthesis of this study is to analyze the relationship between investment, labor, ICT, and NTP on agricultural productivity, both directly and indirectly through human capital and human development in the PPU, which has been designated as the new IKN area. The evaluation using MRA revealed five main outcomes. First, there is a significant direct relationship between ICT and human development. Second, both labor and ICT are significantly associated with agricultural productivity. Third, labor, when moderated by human development, has a significant impact on agricultural productivity. Fourth, the relationship between human capital and human development in relation to agricultural productivity is not significant. Fifth, investment and NTP were found to have an insignificant effect on human capital, human development, and agricultural productivity, whether directly or when moderated by human capital and human development on agricultural productivity.

Through the analysis of data during 2015–2023, the exploration results indicate that the development of investment, NTP, and human capital in the IKN has not yet reached an optimal stage in influencing agricultural productivity. Thus far, only the labor variable has demonstrated direct implications for agricultural productivity, both directly and indirectly through human development. Although ICT also exerts a significant direct influence on agricultural productivity, it has not been fully leveraged. To enhance agricultural productivity, stakeholders in the agricultural sector should adopt a collective and strategic approach. An urgent transition is necessary to promote human capital through an integrated and accelerated investment program within the agricultural sector. Additionally, stakeholders must focus on empowering farmers by enhancing their technological skills, which will further boost agricultural productivity. It is also important to recognize that risks impacting agricultural productivity exist within the NTP. The government must consistently focus on mitigating the risks of losses for farmers in IKN while promoting prosperity. This can be achieved through various measures, such as providing extension services and training facilities, ensuring the availability of seeds, fertilizers, and other agricultural equipment, and establishing partnerships through an agricultural contract system with both private and public corporations. Besides, implementing subsidy and incentive policies for high-achieving farmers is essential. Overall, this study has certain limitations, particularly regarding the restricted data observations and concepts. Future research should consider incorporating long-term data sets. Also, it is recommended to expand the agricultural productivity model by including additional dimensions beyond the current variables.

Acknowledgment

The authors would like to thank the Faculty of Economics and Business - Universitas Mulawarman for supporting this work through grant support in 2024.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Junaidi, A., Gani, I., Darma, D. C.; Design: Busari, A., Kurniawan A., E.; Data collection or processing: Busari, A., Kurniawan A., E., Gani, I.; Statistical analyses: Junaidi, A., Darma, D. C.; Literature search: Kurniawan A., E., Gani, I., Darma, D. C.; Writing, review and editing: Junaidi, A., Busari, A.

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