# A Sustainable Economic Model for Organic Coffee Production in Indonesia: Integrating Local Wisdom and Key Agricultural Factors

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This study investigates the determinants of coffee production among smallholder farmers in Indonesia, focusing on factors such as land area, climate change, capital investment, labour availability, and coffee prices. Utilizing a structured questionnaire for data collection, the research employs Partial Least Squares Structural Equation Modelling (PLS-SEM) via Smart-PLS software to analyse both direct and moderating effects of these variables on coffee production. The findings indicate that increased land size and capital investment significantly enhance coffee yields. Conversely, climate change adversely impacts coffee production through detrimental weather patterns and elevated temperatures. Additionally, issues related to labour availability are identified as critical barriers to improving farming efficiency. The study also reveals that coffee prices mediate the relationships between these variables, with higher prices incentivizing increased production. This research contributes to theoretical understanding by elucidating the dynamics of price volatility and agricultural yields within the coffee market. It offers practical recommendations for stakeholders, advocating for policies aimed at enhancing land consolidation, promoting climate-smart agricultural practices, and improving access to financial services for coffee farmers. The study acknowledges limitations related to its geographic focus and cross-sectional design, suggesting avenues for future research at diverse geographical scales and production levels.

***Keywords:*** Coffee Production, Climate Change, Capital Investment, PLS-SEM, Coffee Prices.

## Introduction

### *Background*

Coffee is among the most valuable agricultural commodities worldwide, significantly contributing to the economies of numerous countries. As the fourth-largest coffee producer globally, Indonesia occupies a crucial position in the international coffee market. The coffee sector in Indonesia is not only a primary source of income for millions of smallholder farmers but also serves as a vital export commodity. The country produces both Arabica and Robusta coffee varieties, which dominate production due to their adaptability to lower altitudes and diverse climatic conditions. Despite Indonesia's prominent role in the global coffee market, the sector encounters various challenges that adversely affect productivity, profitability, and sustainability. Smallholder farmers, who constitute the backbone of coffee production in Indonesia, bear the brunt of these challenges. They face significant risks stemming from price volatility, climate change, limited access to funding, labor shortages, and restricted agricultural land. These factors not only influence the yields and quality of the coffee beans but also impact the overall well-being of the farmers and Indonesia's standing in the international coffee economy. Understanding the intricate relationships between these variables and coffee production is essential for formulating effective strategies to enhance the productivity, profitability, and sustainability of the Indonesian coffee industry. By addressing these interconnected challenges, stakeholders can develop targeted interventions that support smallholder farmers and strengthen Indonesia's position in the global coffee market.

### *Coffee Production in Indonesia: Key Challenges*

Indonesia, as a major coffee producer, confronts numerous challenges within its coffee industry, particularly influenced by factors such as global coffee price volatility, climatic variations, labor dynamics, and access to credit. These interconnected issues complicate the ability of farmers to adopt long-term agricultural strategies. A significant challenge faced by Indonesian coffee producers is the instability of coffee prices. The global market exerts a profound influence on coffee pricing, and the inherent volatility in these prices disproportionately affects small-scale farmers, who often struggle to absorb financial losses. When coffee prices are high, farmers are incentivized to reinvest their profits by expanding their cultivated areas and adopting new production technologies. Conversely, when prices decline, farmers tend to reduce their input expenditures, abandon coffee cultivation, and shift towards more stable crops. This cyclical nature of investment and disinvestment can destabilize local coffee production and hinder long-term planning. Climate change represents an escalating concern for coffee production, particularly for the Arabica variety, which is highly sensitive to temperature fluctuations and altered rainfall patterns. Research indicates that climate change has reduced the suitable growing areas for Arabica coffee, compelling farmers to extend their cultivation into cooler regions (Bunn et al., 2015). Furthermore, the adverse effects of climate change do not only diminish coffee yields but also compromise the quality of the beans due to various environmental stresses placed on the crops. This dual impact on both quantity and quality poses significant risks for farmers who rely on coffee as their primary source of income. Access to credit is another critical challenge facing smallholder coffee farmers in Indonesia. Many farmers lack the necessary capital to invest in improved farming practices, modern tools, and essential inputs such as fertilizers and pesticides. Financial constraints severely limit their ability to adopt advanced technologies that could enhance both the quality and quantity of coffee production. Additionally, labor shortages, particularly during peak harvest times, can lead to disastrous outcomes, resulting in lower yields and subpar quality of coffee beans (Nyemeck Binam et al., 2003). This lack of labor not only affects immediate production but also undermines the overall sustainability of coffee farming in the region.

### *Importance of Key Variables in Coffee Production*

This study examines five critical factors influencing coffee production in Indonesia: land area, climate change, capital investment, labor availability, and current coffee prices. While these variables are commonly identified in broader analyses of agricultural productivity, their interrelations within the Indonesian coffee sector warrant particular attention to enhance yield and sustainability (Nugroho et al., 2020; Pratama et al., 2019; Tanjung et al., 2022; Utamia, Indriantob, & Pratamac, 2019). Investment in agriculture, especially in crops like tea, is often characterized by the extensive land area dedicated to production, which directly impacts productivity. Larger farms can capitalize on economies of scale, allowing farmers to apply higher quantities of inputs per hectare, thus resulting in greater yields. However, in Indonesia, where smallholder farming predominates, expanding land area presents challenges due to land scarcity and competition with other agricultural uses (Astuty et al., 2022b; Atrizka et al., 2020; Nu'man et al., 2020; Saragih et al., 2020; Siregar et al., 2023). The escalating influence of climate change on coffee production cannot be overlooked. Rising temperatures, altered rainfall patterns, and increased pest and disease incidence collectively contribute to declining coffee yields. Agricultural productivity, particularly in coffee cultivation, is vulnerable to the impacts of climate change, which disproportionately affect smallholder farmers who typically have fewer resources to adapt (Danilwan & Pratama, 2020; Pratami et al., 2022; Silviani, Nisa, & Pratama, 2022). Capital investment is another essential factor, as access to financial resources is crucial for improving farming practices, tools, and inputs. The study highlights that access to capital is particularly relevant for smallholder farmers in Indonesia, whose operations are often marginal, limiting their ability to invest in productivity-enhancing technologies (Astuty et al., 2022a; Atrizka & Pratama, 2022; Pratama et al., 2024). Labor availability plays a vital role in coffee production, particularly during planting and harvesting seasons (Ikhsan et al., 2024). The ease of access to labor significantly influences the efficiency of farming practices and the quality of the harvested beans. However, rural areas in Indonesia face labor shortages due to urban migration and an aging population, exacerbating the challenges of coffee production. As a globally traded commodity, coffee prices fluctuate in response to external market forces, often beyond the control of farmers. These price dynamics have a direct impact on farmers' earnings and their willingness to invest in future production. High coffee prices typically encourage expansion and reinvestment, while low prices lead to reduced production and lower investment levels.

This study primarily assesses the correlation among land area, climate change, capital investment, labor availability, and coffee prices on coffee production in Indonesia. Additionally, it seeks to establish the moderating role of coffee prices within these relationships. Specifically, the research aims to explore several key questions: To what extent do variations in land area impact coffee production in Indonesia? How does climate change affect coffee production in the country? In what ways does financing influence coffee production and farming operations? How does the availability of labor constrain coffee production levels? Finally, this study seeks to elucidate the moderating role of coffee prices in the relationships between land area, climate change, capital investment, labor availability, and coffee production. This research provides valuable insights to the existing literature on coffee production, particularly concerning smallholder farmers in Indonesia. Understanding the interdependencies among critical factors such as land area, climate change, capital investment, labor availability, and coffee prices is essential for developing strategies aimed at enhancing per-hectare productivity and ensuring the sustainability of the Indonesian coffee industry. Given the increasing emphasis on sustainable agriculture in light of climate change and global market volatility, the findings of this study have significant implications for policymakers, agricultural extension services, and farmers themselves. The insights gained will inform approaches to increase coffee productivity in future environmental and economic conditions, particularly emphasizing the impact of coffee prices as a moderating variable. By addressing these factors, this study aims to provide a comprehensive framework for enhancing the resilience and sustainability of coffee production in Indonesia.

## Literature Review

### *Relationship Between Land Area and Coffee Production*

This study investigates the correlation between land area and the efficiency of agricultural production, with a specific focus on coffee farming. The literature indicates a consensus among researchers that larger farm sizes tend to yield higher outputs due to factors such as economies of scale, improved resource utilization, and enhanced management practices. According to a prior study the farm size significantly influences coffee production in Kisii County, Kenya. Their findings suggest that larger farms achieve higher yields per hectare because they can dedicate more land to coffee cultivation compared to smallholders who may grow multiple crops. Moreover, larger properties are more conducive to implementing quality-enhancing technologies, thereby boosting production. Similarly, Wollni & Zeller (2007) highlighted that larger farmers in Costa Rica experience greater productivity due to better access to resources, particularly labor, inputs, and specialty coffee markets. This access allows large-scale farmers to adopt advanced farming practices and techniques, further increasing their yields. Scholars also reported that expanding the area allocated to coffee production in Ethiopia positively impacts both the quality and quantity of coffee produced.

Larger farmers are better positioned to implement improved agricultural practices, such as mechanization for planting and weeding, as well as organic farming techniques that enhance coffee quality. Supporting this, Barham et al. (2011) demonstrated in their study in Southern Mexico that larger land parcels facilitate better agricultural practices, such as terracing and shade-grown coffee, which not only boost production but also promote ecological diversity. While the physical size of the farm plays a crucial role in productivity, it is also closely linked to access to better markets. Binswanger & Rosenzweig (1986) argued that larger farms, particularly in developing countries, benefit from increased access to capital and credit facilities, which enable them to adopt improved farming technologies. These advancements contribute to more efficient production and higher yields. The research conducted by Moguel & Toledo (2001) in Mexico provides additional insights into traditional coffee systems, indicating that larger-scale coffee farms yield significantly more coffee and support a greater diversity of plant and animal species, enhancing soil fertility and long-term yields. This perspective is echoed in the study by researchers in Yirga Cheffe, Southern Ethiopia, where both male and female coffee farmers with larger plots achieved higher yields due to effective land management practices and technologies, including agroforestry and soil conservation.

In the Indonesian context, researchers extended this economic relationship, finding a significant increase in coffee production correlating with larger farm sizes. Their research indicates that increased land area positively affects input usage, labor efficiency, and mechanization, leading to higher yields on larger farms compared to smaller ones. This observation aligns with findings from Southern Ethiopia, where land expansion is associated with increased coffee production. Furthermore, researchers in Tanzania noted that greater farm sizes resulted in higher coffee yields and incomes, offering farmers greater resilience against crop failures and market instability. A prior study similarly identified farm size as a critical factor in coffee productivity in India, asserting that larger farms benefit from better access to irrigation and advanced technologies. Across these studies, a clear pattern emerges: the amount of land available significantly influences coffee production levels. Larger farms not only achieve standardized outputs but also adopt superior farming practices and gain access to better markets, ultimately leading to higher coffee yields when compared to small-scale farming operations.

**H1:** It was also found that there is a positive correlation between land area and Coffee Production.

### *Relationship Between Land Area and Coffee Production*

Global climate change has emerged as a critical factor undermining agricultural productivity, with coffee production particularly vulnerable to shifting climatic conditions. Numerous studies have explored the impacts of rising temperatures, altered rainfall patterns, and extreme weather events on coffee quality and average yields. This section synthesizes findings from various research efforts to illustrate the significant role that climate change plays in coffee production and to formulate Hypothesis H2. A recurrent conclusion across multiple publications is the negative impact of increasing temperature levels on coffee production. A prior study described that rising mean temperatures and temperature fluctuations constrain the geographic areas suitable for coffee cultivation, with Arabica coffee being more susceptible to these changes than Robusta. Supporting this view, Bunn et al. (2015) project that temperature increases could lead to a reduction of nearly 50% in Arabica coffee production by 2050. For instance, in Tanzania, rising temperatures have been correlated with decreased yields, as illustrated in various data visualizations. Shifts in precipitation patterns, particularly erratic rainfall and prolonged dry seasons, have also been shown to adversely affect coffee production. Pham et al. (2019) emphasize that irregular rainfall disrupts the flowering process of coffee plants, resulting in lower yields.

In Central America, Bunn et al. (2015) modeled future climate scenarios and found that, without adaptation measures, one-third of existing coffee-growing areas may become unsuitable due to changing precipitation patterns. Moguel & Toledo (2001) further noted that extended dry seasons exacerbate pest problems, compounding the negative effects on coffee yields. Climate change also heightens the risk posed by pests and diseases. Warmer temperatures have been linked to the spread of the coffee berry borer and leaf rust disease. Results of a prior study demonstrated that elevated temperatures and humidity levels, particularly in Latin America, create optimal conditions for pest proliferation, resulting in significant crop losses. Similarly, Craparo et al. (2015) reported a 50% decrease in Arabica coffee yields in Tanzania, attributing this decline primarily to increased pest populations driven by climate change. Several studies suggest that adaptation strategies may mitigate some of the adverse impacts of climate change on coffee production. Bunn et al. (2015) proposed agroforestry systems and the introduction of drought-resistant coffee varieties as viable solutions.

Likewise, Pham et al. (2019) advocated for the development of climate-resilient coffee production systems, emphasizing improved irrigation techniques and effective shade management. It is important to note that the effects of climate change are not uniform across different regions, with altitude playing a significant role in determining coffee production outcomes. A prior study found that higher-altitude regions may be less affected by rising temperatures compared to low-altitude areas, which are at risk of losing their suitability for coffee cultivation. Conversely, Jaramillo et al. (2011) suggested that climate change could create favorable conditions for coffee cultivation in higher elevation sites, offering a potential refuge for coffee production. The literature reviewed consistently underscores the detrimental impacts of climate change on coffee production, highlighting the challenges posed by rising temperatures, variability in precipitation patterns, and increased pest infestations. Despite evidence suggesting that vulnerability to climate change is escalating, the potential for adaptation strategies to mitigate these negative effects is acknowledged. However, the overall trend analysis points to a concerning scale of loss in coffee production. Therefore, the second hypothesis of this study is:

**H2:** Climate change has a strong implication for Coffee Production.

### *Relationship Between Capital Investment and Coffee Production*

Access to capital is a critical driver of agricultural yield, particularly in coffee production, as it enables producers to adopt improved practices that enhance productivity and upgrade physical infrastructure. Numerous studies have investigated the role of both international and local investment in boosting coffee production, especially in developing countries. In his analysis of the impact of foreign direct investment (FDI) on coffee production in Latin America, A prior study found that many farmers received capital inflows from foreign investors, which allowed them to purchase advanced machinery, increase production capacity, and adopt modern agricultural techniques. This influx of capital significantly improved productivity, particularly for smallholder farmers who previously lacked the financial means to invest in necessary inputs. The study highlights that access to funding directly influences output levels, as mechanization reduces reliance on labor, thus increasing efficiency.

Similarly, prior literature emphasized the importance of investment in irrigation infrastructure, noting that coffee is heavily dependent on water resources. Their assessment of Mexican farmers revealed that those who received subsidies for establishing irrigation systems achieved yield increases of up to 30% compared to those unable to afford such investments. This underscores the importance of capital in mitigating environmental challenges and stabilizing future production. In the Indonesian context, many scholars highlighted the role of social and financial capital. Their study found that coffee cooperatives, supported by local and international investors, could mobilize necessary funds that smallholder farmers often struggle to pool together for purchasing inputs such as fertilizers and quality seeds. Moreover, these cooperatives facilitated knowledge sharing and the adoption of proven agricultural practices, resulting in significantly boosted yields. A prior study conducted in Rwanda's coffee sector, demonstrating how capital investment improved processing facilities, thereby enhancing the quality of beans sold in premium markets.

Their findings indicate that capital investment is pivotal not only for increasing production but also for improving the quality of the final product, which in turn boosts profitability. Scholars examined capital practices related to coffee production in Brazil, focusing on government subsidies and private sector investments. Their results indicated that access to capital for purchasing seeds, fertilizers, and other inputs whether through government support or commercial credit enabled farmers to adopt improved inputs and increase productivity by as much as 40%. This study highlighted that access to capital is particularly crucial for small and medium-sized farms, as it levels the playing field against larger, established coffee producers. Finally, according to the prior literature it is found that expanding coffee plantation scale requires substantial financial capital. In a study conducted with farmers in Ethiopia, it was observed that those able to secure investment financing could increase the size of their coffee farms, which had a direct relationship with total production levels. This research further supports the premise that financial input is essential for the growth of coffee production areas and the enhancement of coffee farming operations. The existing literature on successful coffee production consistently indicates a strong positive relationship between capital investment and coffee yield. Investments facilitate the application of technology in farming, improve infrastructure, and enhance access to quality markets, ultimately leading to better production outcomes. Thus, the following hypothesis is proposed:

**H3:** Capital investment has a direct positive correlation with Coffee Production.

### *Relationship Between Number of Farmers and Coffee Production*

The availability of labor, including the number of farmers, significantly influences productivity levels in coffee farming. In agricultural systems, labor is intrinsically linked to the effective management of crops, proper harvesting techniques, and the overall execution of farming practices. A substantial body of literature has explored the relationship between labor and coffee production, particularly in regions where coffee cultivation is labor-intensive. For instance, Nyemeck Binam et al. (2003) examined technical efficiency among coffee producers in Côte d'Ivoire, finding that labor availability emerged as a critical factor alongside variables such as contact with extension agents, education levels, and access to coffee cultivation knowledge. Their study concluded that higher farm incomes were associated with greater labor availability, which facilitated better crop organization and yield management. Conversely, capital investments were also identified as essential for enhancing practices that contribute to coffee production.

Similarly, many scholars highlighted that coffee production in Jamaica heavily relies on a substantial labor force, especially during harvest time. They noted that labor scarcity could lead to reduced output, illustrating the vital role of labor in maintaining production levels. A prior study focused on Papua New Guinea, where labor constraints led to delayed harvesting, and adversely affecting coffee quality. Their findings indicated that larger coffee farms with sufficient labor resources could manage land and pest control more effectively, thereby improving both the quality and quantity of coffee produced. Scholars also reinforced this view, asserting that the number of available farmers is directly related to the capability of managing effective coffee farms. Adequate labor facilitates timely and efficient execution of crucial agronomic operations, such as pruning, fertilization, and harvesting. In a study conducted in Ghana, results of a prior study identified labor shortages as a significant barrier to coffee cultivation among smallholder farmers.

Their research corroborated earlier findings, revealing that farms with sufficient labor resources achieved higher yields due to the timely execution of farming activities. Moreover, the quality of coffee produced was positively influenced by labor availability, ensuring that beans were harvested at the optimal time. Prior literature further underscored the importance of labor, noting that small-scale coffee farmers who could employ more labor were better positioned to implement labor-intensive practices, such as shade management and weeding, which led to improved yields. This affirms the notion that labor is essential not only for basic farming functions but also for the adoption of superior agricultural techniques that enhance productivity. Scholars also extended this analysis to post-harvest processes, observing that farms with greater labor input in coffee processing achieved better quality and, consequently, better market prices.

Moreover, a prior study examined that the impact of labor on small-scale coffee farmers in Tanzania, concluding that labor availability significantly affected coffee yields. They found that small farming operations often rely heavily on labor, and challenges related to workforce availability could substantially hinder production. Prior literature reiterated that coffee production in Jamaica is closely tied to labor availability, with limited labor resources leading to decreased output, especially during the critical harvesting season. Overall, the literature consistently demonstrates that the presence of farmers and labor resources is a fundamental determinant of coffee production output. Regions endowed with ample labor resources are better equipped to facilitate the diverse activities essential to the agricultural sector, ultimately enhancing both the quality of the produce and the overall yields. Therefore, the following hypothesis is proposed:

**H4:** The number of farmers has a direct impact and bears a positive relationship with the production of Coffee.

### *Moderating Impact of Coffee Prices on Coffee Production*

Coffee has been the subject of extensive research within agricultural economics, particularly concerning its prices and production dynamics. Prices are a critical determinant of profitability and significantly influence farmers' decisions regarding coffee production, investment, and productivity. Empirical analyses have shown that rising prices typically encourage increased production levels, prompting farmers to expand their coffee acreage or enhance their production practices. Conversely, low prices can stifle investment in new technologies, resulting in reduced yields or even prompting farmers to switch to more profitable crops. For example, a study examining the fluctuations in coffee export volumes from Indonesia found that international coffee prices directly affect these volumes, as higher prices incentivize increased production. Prior literature further emphasizes that social network capital plays a crucial role in farmers' efforts to secure better coffee prices in Uganda, illustrating that while prices are vital for determining production levels, social structures can influence how farmers interpret and respond to price signals.

In related research, scholars explored price transmission mechanisms within coffee markets, noting that international price signals often elicit immediate responses in local production decisions. They observed asymmetric price transmission, where price increases tend to be communicated to producers more effectively than price declines. Prior literature highlights this phenomenon, indicating that production tends to be more responsive to rising prices, leading to volatility in production as it reacts to price fluctuations. However, the relationship between prices and production is not always straightforward. Other exogenous factors, such as access to credit, labor availability, and land ownership, also play critical roles in shaping farmers' responses to price changes. Cross-sectional analysis revealed that only farmers with access to resources or social capital were able to leverage high prices to boost production effectively. This finding suggests that while price is an essential factor, its influence is mediated by other conditions, including capital and labor availability. This study seeks to investigate how coffee prices impact production and how these prices may moderate other critical factors influencing production, such as land area, conditions, and labor availability in coffee-producing regions. Thus, we propose the following hypothesis:

**H5:** Coffee Prices moderate the relationship between Land Area, Labour Availability, and Coffee Production, such that higher prices strengthen the positive impact of these factors on production.

## Research Method

### *Measurement*

The present research employed a structured questionnaire to gather data from smallholder coffee farmers in Indonesia. The questionnaire was designed to investigate various variables outlined in the theoretical model, including coffee land area, perceptions of climate change, accessibility to capital, availability of labor, and coffee prices. It was organized into several sections: demographics, beliefs about climate change and sources of funding, labor availability, and market forces. To ensure validity and reliability, the questionnaire utilized previously developed and validated scales wherever possible. Participants responded to the questions using a five-point Likert scale, with options ranging from "Strongly Disagree" (1) to "Strongly Agree" (5). For example, to assess perceptions of climate change, the item "Climate variability has negatively impacted my coffee production" was adapted from Jaramillo et al. (2011). Hypothesis two, which posits a positive correlation between investment capital and the investments made by young coffee farmers, was evaluated based on the amount of capital invested in their coffee farms and access to credit, with items derived from Songa & Cheluget (2016). Additionally, the moderating variable of coffee prices was measured through a statement reflecting farmers' perceptions of price fluctuations and their consequent effects on production. This structured approach allowed for a comprehensive assessment of the various factors influencing coffee production among smallholders in Indonesia.

### Data Analysis Methods

Data analysis for this study was conducted using Smart-PLS 3.0 software, which employs partial least squares structural equation modeling (PLS-SEM). This methodology was selected due to its flexibility in incorporating multiple latent factors within the model and its capacity to handle non-normally distributed data effectively. Additionally, Smart-PLS facilitates the testing of direct relationships among variables in the conceptual model, as well as the examination of moderating effects. The analysis followed a two-step approach: first, the development and validation of the measurement model, followed by the assessment of the structural model.

### Measurement and Structural Model

Smart-PLS was utilized to confirm the reliability and validity of the constructs employed in the study. Internal consistency was assessed using Cronbach's alpha and composite reliability (CR), both of which are expected to exceed a threshold of 0.7. To evaluate convergent validity, average variance extracted (AVE) was calculated, with values above 0.5 indicating sufficient convergent validity. Discriminant validity was confirmed using the Fornell-Larcker criterion and the Heterotrait-Monotrait (HTMT) ratio, ensuring that each construct remained distinct. Once the measurement model was validated, the structural model was analyzed to test the hypothesized relationships. Path coefficients, standard deviations, t-values, and p-values were generated through bootstrapping with 500 subsamples, which allowed for assessing the significance of the relationships. Smart-PLS also provided insights into the moderating effect of coffee prices on the relationships between independent variables, such as land area, climate change, capital investment, and coffee production. Through this comprehensive analysis using Smart-PLS, we were able to elucidate the direct and moderating effects of various factors, including coffee land area, climate change, capital investment, labor availability, and coffee prices on coffee production in Indonesia.

## Results

### Measurement Model

In the initial step of our analysis, we focused on measuring reflective constructs to assess reliability and validity. This involved evaluating outer loadings, CR, Cronbach's alpha, average variance extracted (AVE), and the HTMT ratio. Outer loadings are critical indicators, with recommended values typically falling between 0.4 and 0.6. To ensure robustness, we set additional criteria for the constructs: Cronbach's alpha was expected to be 0.7 or higher, AVE should exceed 0.5, and the Full Collinearity Variance Inflation Factors (VIFs) needed to be below the threshold indicating multi-collinearity. These measures collectively affirm the reliability and validity of the constructs used in our study.

**Table 1:** Construct Reliability and Validity.

| Constructs | Items | Loadings | Alpha | CR | AVE |
|---|---|---|---|---|---|
| | CC1 | 0.853 | | | |
| | CC2 | 0.843 | | | |
| Climate Change | CC3 | 0.783 | 0.846 | 0.890 | 0.620 |
| | CC4 | 0.708 | | | |
| | CC5 | 0.739 | | | |
| | CIN1 | 0.861 | | | |
| | CIN2 | 0.784 | | | |
| Capital Investment | CIN3 | 0.875 | 0.858 | 0.898 | 0.641 |
| | CIN4 | 0.788 | | | |
| | CIN5 | 0.677 | | | |
| | CP1 | 0.817 | | | |
| | CP10 | 0.719 | | | |
| | CP2 | 0.791 | | | |
| | CP3 | 0.786 | | | |
| Coffee Production | CP4 | 0.784 | 0.930 | 0.941 | 0.614 |
| | CP5 | 0.826 | | | |
| | CP6 | 0.810 | | | |
| | CP7 | 0.751 | | | |
| | CP8 | 0.803 | | | |
| | CP9 | 0.742 | | | |
| | CPR1 | 0.849 | | | |
| Coffee Prices | CPR2 | 0.905 | | | |
| | CPR3 | 0.881 | | | |
| | CPR4 | 0.874 | 0.900 | 0.930 | 0.770 |
| Land Area | LA1 | 1.000 | | | |
| Number of Farmers | NF1 | 1.000 | | | |

Table 1 summarizes the loadings, Cronbach's alpha, CR and AVE for each construct in the proposed framework. The t-values for all items associated with the constructs, including Climate Change, Capital Investment, and Coffee Production, exceed the threshold of 0.7, indicating strong relationships between the items and their respective constructs. Each construct demonstrates good internal consistency, as evidenced by Cronbach's Alpha values surpassing the 0.7 benchmark (e.g., Climate Change: 0.846; Capital Investment: 0.858). The CR values for all constructs also exceed the 0.7 threshold, further confirming their internal consistency reliability (e.g., Coffee Production: 0.941; Coffee Prices: 0.930). Additionally, the AVE values for all constructs exceed the 0.5 threshold, validating convergent validity (e.g., Coffee Production: 0.614; Coffee Prices: 0.770). This indicates that the constructs account for a significant portion of the variance in their indicators. Collectively, these results affirm the reliability and validity of the constructs, thereby supporting the measurement model utilized in this study.

**Table 2:** Fornell Larcker.

| | CC | CIN | CP | CPR | LA1 | NF1 |
|---|---|---|---|---|---|---|
| CC | 0.787 | | | | | |
| CIN | 0.569 | 0.800 | | | | |
| CP | 0.565 | 0.481 | 0.784 | | | |
| CPR | 0.606 | 0.458 | 0.601 | 0.878 | | |
| LA1 | 0.317 | 0.282 | 0.627 | 0.471 | 1.000 | |
| NF1 | 0.320 | 0.225 | 0.573 | 0.468 | 0.704 | 1.000 |

Table 2 presents the square root of the AVE along the diagonal (in bold) and the correlations between the constructs off-diagonal. For the model to exhibit discriminant validity, the diagonal values, representing the square roots of the AVE, must be higher than the correlations between constructs. The results indicate that the square root of the AVE for each construct, such as Climate Change (0.787) and Capital Investment (0.800), is indeed greater than the correlations among the constructs. This finding confirms good discriminant validity, suggesting that each construct is more strongly associated with its indicators than with other constructs in the model. Thus, the constructs can be considered distinct, reinforcing the robustness of the measurement model.

**Table 3:** Cross-Loadings.

| | CC | CIN | CP | CPR | LA1 | NF1 |
|---|---|---|---|---|---|---|
| CC1 | **0.853** | 0.447 | 0.498 | 0.593 | 0.281 | 0.276 |
| CC2 | **0.843** | 0.419 | 0.502 | 0.520 | 0.270 | 0.321 |
| CC3 | **0.783** | 0.514 | 0.397 | 0.378 | 0.195 | 0.190 |
| CC4 | **0.708** | 0.435 | 0.382 | 0.372 | 0.287 | 0.223 |
| CC5 | **0.739** | 0.444 | 0.428 | 0.491 | 0.210 | 0.231 |
| CIN1 | 0.528 | **0.861** | 0.398 | 0.439 | 0.217 | 0.187 |
| CIN2 | 0.448 | **0.784** | 0.294 | 0.347 | 0.107 | 0.097 |
| CIN3 | 0.418 | **0.875** | 0.406 | 0.321 | 0.251 | 0.174 |
| CIN4 | 0.337 | **0.788** | 0.295 | 0.223 | 0.175 | 0.085 |
| CIN5 | 0.493 | **0.677** | 0.460 | 0.439 | 0.312 | 0.289 |
| CP1 | 0.430 | 0.419 | **0.817** | 0.497 | 0.564 | 0.502 |
| CP10 | 0.465 | 0.364 | **0.719** | 0.429 | 0.394 | 0.428 |
| CP2 | 0.433 | 0.434 | **0.791** | 0.471 | 0.530 | 0.473 |
| CP3 | 0.417 | 0.396 | **0.786** | 0.479 | 0.435 | 0.363 |
| CP4 | 0.451 | 0.349 | **0.784** | 0.497 | 0.539 | 0.473 |
| CP5 | 0.429 | 0.395 | **0.826** | 0.506 | 0.554 | 0.509 |
| CP6 | 0.415 | 0.378 | **0.810** | 0.482 | 0.531 | 0.477 |
| CP7 | 0.471 | 0.388 | **0.751** | 0.461 | 0.447 | 0.421 |
| CP8 | 0.495 | 0.339 | **0.803** | 0.467 | 0.476 | 0.445 |
| CP9 | 0.434 | 0.296 | **0.742** | 0.411 | 0.412 | 0.377 |
| CPR1 | 0.491 | 0.303 | 0.511 | **0.849** | 0.409 | 0.396 |
| CPR2 | 0.556 | 0.417 | 0.496 | **0.905** | 0.422 | 0.460 |
| CPR3 | 0.537 | 0.399 | 0.528 | **0.881** | 0.427 | 0.413 |
| CPR4 | 0.542 | 0.480 | 0.568 | **0.874** | 0.394 | 0.379 |
| LA1 | 0.317 | 0.282 | 0.627 | 0.471 | **1.000** | 0.704 |
| NF1 | 0.320 | 0.225 | 0.573 | 0.468 | 0.704 | **1.000** |

Cross-loadings are essential for assessing discriminant validity and are detailed in Table 3. Each item is expected to load higher on its respective construct than on any other construct. The results indicate that each item indeed shows higher loadings on its designated construct. For instance, item CC1 loads 0.853 on the Climate Change construct, while exhibiting significantly lower loadings on other constructs. This observation further reinforces the discriminant validity of the constructs. Additionally, the HTMT ratio serves as another criterion for evaluating discriminant validity. To establish adequate discriminant validity, HTMT values should ideally be below 0.85. Table 4 illustrates that the HTMT values between all constructs are well below this threshold, with values such as 0.661 between Climate Change and Capital Investment, and 0.654 between Coffee Prices and Coffee Production. These findings confirm the discriminant validity of the constructs within the model, enhancing the credibility of the measurement framework.

**Table 4:** Discriminant Validity (HTMT).

| | CC | CIN | CP | CPR | LA1 | NF1 |
|---|---|---|---|---|---|---|
| CC | | | | | | |
| CIN | 0.661 | | | | | |
| CP | 0.634 | 0.518 | | | | |
| CPR | 0.685 | 0.501 | 0.654 | | | |
| LA1 | 0.344 | 0.287 | 0.646 | 0.496 | | |
| NF1 | 0.343 | 0.225 | 0.592 | 0.495 | 0.704 | |

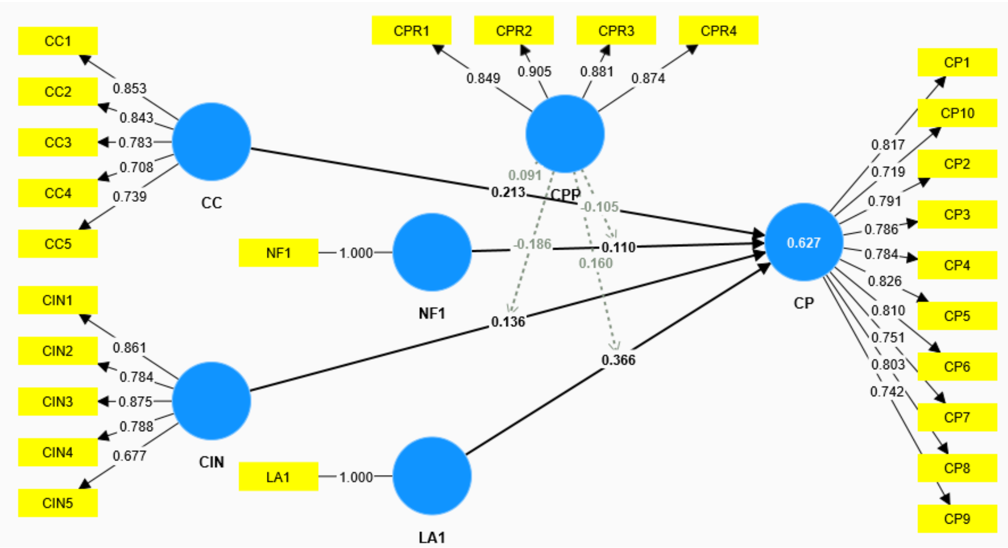


**Figure 1:** Measurement Assessment Model.

This figure visually illustrates the measurement model, highlighting the relationships between the latent constructs and their corresponding indicators. Each indicator's loading on its respective construct is clearly displayed, reinforcing the high factor loadings reported in the accompanying tables. The strong associations depicted in the figure underscore the reliability and validity of the constructs, providing a comprehensive overview of how each indicator contributes to its construct within the model.

### *Structural Model*

All path coefficients in the analysis are significant at the 0.05 level, as indicated by their respective p-values. The results, summarized in Table 5, reveal several key relationships. The path from climate change to coffee production shows a coefficient of 0.213, with a t-value of 4.129 and a p-value less than 0.001, demonstrating a significant positive relationship between perceptions of climate change and coffee production. Similarly, the path coefficient for capital investment to coffee production is 0.136 ($t = 3.516$, $p < 0.001$), indicating that capital investment significantly positively impacts coffee production. The relationship between coffee prices and coffee production also reveals a substantial effect, with a path coefficient of 0.191 ($t = 4.308$, $p < 0.001$), suggesting that higher coffee prices are associated with increased production levels. Furthermore, the analysis shows that land area has a considerable influence on coffee production, with a path coefficient of 0.366 ($t = 7.391$, $p < 0.001$), indicating that a larger land area significantly enhances production outcomes. Additionally, the number of farmers involved in coffee production contributes positively, with a path coefficient of 0.110 ($t = 2.375$, $p = 0.018$), highlighting the importance of labor availability in boosting coffee yields. Moreover, the analysis identifies significant moderating effects, particularly regarding the interaction of coffee prices with land area and climate change. The interaction with land area yields a coefficient of $\beta = 0.160$ ($t = 3.254$, $p = 0.001$), indicating that coffee prices moderate the relationship between land area and coffee production. Likewise, the interaction of coffee prices with climate change shows a coefficient of $\beta = 0.091$ ($t = 2.567$, $p = 0.010$), suggesting that coffee prices also play a moderating role in the effects of climate change on production outcomes.

**Table 5:** Path Analysis.

| Relationships | Beta | Standard deviation | T statistics | P values |
|---|---|---|---|---|
| CC -> CP | 0.213 | 0.051 | 4.129 | 0.000 |
| CIN -> CP | 0.136 | 0.039 | 3.516 | 0.000 |
| CPR -> CP | 0.191 | 0.044 | 4.308 | 0.000 |
| LA1 -> CP | 0.366 | 0.050 | 7.391 | 0.000 |
| NF1 -> CP | 0.110 | 0.046 | 2.375 | 0.018 |
| CPR x NF1 -> CP | -0.105 | 0.048 | 2.172 | 0.030 |
| CPR x LA1 -> CP | 0.160 | 0.049 | 3.254 | 0.001 |
| CPR x CC -> CP | 0.091 | 0.035 | 2.567 | 0.010 |
| CPR x CIN -> CP | -0.186 | 0.037 | 5.085 | 0.000 |

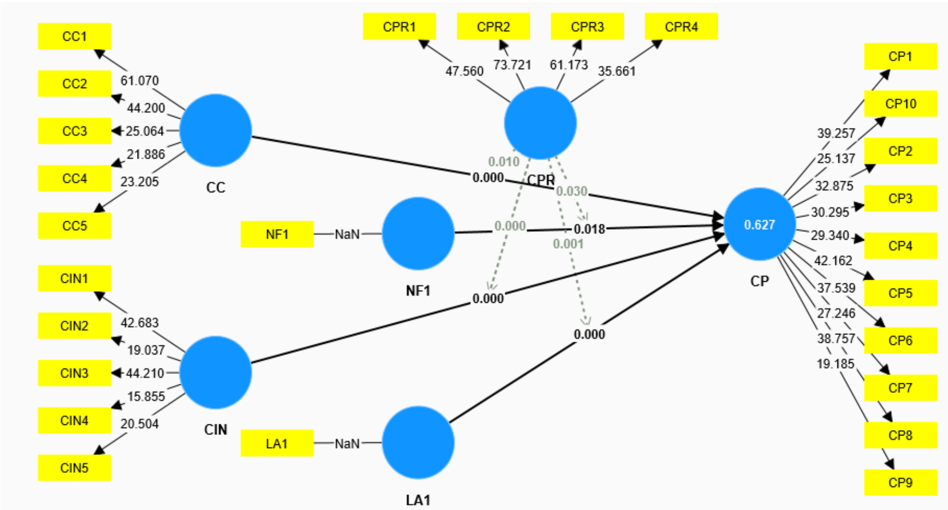


**Figure 2:** Structural Assessment Model.

Figure 2 visually represents the structural model, illustrating the directional relationships between the various constructs, such as the link from climate change to coffee production. The arrows indicate these connections, while the accompanying path coefficients from Table 5 are depicted graphically, emphasizing their significance levels. This model effectively captures the variance in coffee production, underscoring the critical roles of climate change, capital investment, coffee prices, land area, and the number of farmers in shaping production outcomes. Through this visual representation, the interdependencies among these factors become clear, highlighting their collective influence on coffee yield dynamics.

## Discussion and Implication

### *Theoretical Implications*

This research significantly contributes to the expanding literature on agricultural productivity, particularly in the context of coffee production, by investigating the relationships among land area, climate change, capital investment, labor availability, and coffee prices. Several theoretical implications arise from the findings. Firstly, the positive coefficient estimate for land area reinforces previous empirical studies by Wollni & Zeller (2007), which assert that larger farms are typically better equipped with resources and exhibit greater productivity in coffee cultivation. The findings suggest that with more land, farmers can implement improved cultivation techniques, leading to higher yields. This supports the resource-based theory, which posits that increased land availability enables farmers to achieve economies of scale and operate more efficiently. Secondly, the study confirms the detrimental effects of climate change on coffee production, aligning with the research of Bunn et al. (2015), which highlight the adverse impact of weather variability on yields, particularly for Arabica coffee. This research contributes to the discourse on climate resilience by emphasizing that coffee farmers face significant challenges from harsh and unpredictable weather patterns and heightened pest pressures due to climate change. This aligns with broader agricultural literature that underscores the sensitivity of coffee production to environmental fluctuations. Thirdly, the findings underscore the importance of capital investment in enhancing coffee production, consistent with the prior literature, which illustrates how access to financial resources improves farming technologies and infrastructure. The study highlights the necessity of financial capital for managing environmental challenges and enhancing product quality, furthering existing research on the critical role of financial access in supporting resource acquisition and productivity among upland farmers. Finally, the moderating effect of coffee prices introduces a new dimension to the analysis of price influences on production output. This finding supports earlier conclusions in the prior literature, which indicate that rising prices are more likely to stimulate coffee production compared to falling prices, which may deter investment and reduce productivity. The role of prices as a moderating factor elucidates the nonlinear interactions between market dynamics and agricultural decision-making.

### *Practical Implications*

This study provides several crucial recommendations for policymakers, coffee farmers, and agricultural stakeholders aimed at enhancing coffee production. Firstly, the strong link between land area and coffee production suggests that efforts to enhance land aggregation and optimize resource management could significantly boost productivity. According to a prior study increasing land area allows for better resource management and the application of agricultural technologies. Therefore, facilitating smallholder farmers' access to larger or more collectively managed farmland could substantially increase coffee yields. Secondly, given the findings related to climate change, it is essential for policymakers to promote climate-resilient agricultural practices. Encouraging methods such as agroforestry and shade-grown coffee systems, as proposed by Bunn et al. (2015), can help mitigate the adverse effects of climate change on coffee production. Additionally, exploring coping strategies that explain how some farmers achieve good yields under challenging conditions such as drought-resistant coffee varieties and improved rainfall management should be prioritized. Thirdly, enhancing access to capital investment is vital for improving coffee production. Financial institutions and government programs should develop products such as emergency loans or micro-finance options tailored for coffee farmers. Also a prior study determined that increased access to investment capital enables farmers to adopt improved practices, purchase quality inputs, and develop necessary infrastructure. Supporting coffee cooperatives could also help consolidate resources among smallholders, further enhancing production capacity. Lastly, the moderating effect of coffee prices on production underscores the importance of effective price stabilization mechanisms. Ministries and cooperatives should implement policies that support price stability and provide market support, particularly during periods of significant price volatility. This approach would reduce farmers' exposure to price risks and encourage long-term investments in productivity enhancements. Additionally, interventions aimed at improving farmers’ access to market information and their bargaining power can lead to better returns from coffee cultivation.

## Limitations and Future Research Direction

This research has several limitations that suggest avenues for future exploration. Firstly, the study is geographically limited to Indonesian coffee farmers, which restricts the generalizability of the findings to other coffee-producing regions. Future research could benefit from comparisons between coffee-exporting nations in Africa or Latin America, where the social, economic, and environmental contexts differ significantly. This broader perspective would provide valuable insights into the global factors influencing coffee production. Secondly, the cross-sectional nature of the data collected limits the ability to establish causal relationships among the variables. While PLS-SEM effectively constructs the model, subsequent studies should employ longitudinal designs to observe changes over time, particularly regarding the impacts of climate change and price fluctuations on coffee production. Thirdly, this study primarily focuses on smallholder coffee farmers. While they represent a significant segment of coffee producers, large-scale commercial farms may operate under different dynamics. Future research could investigate how the same factors interact with larger, profit-oriented farms, offering a comprehensive view of the relationship between farm scale, productivity, capital, and market volatility. Additionally, while this study examines the mediating effect of coffee prices on key variables and production, it does not address external factors such as government policies, international trade agreements, and technological advancements. Future studies should explore how these elements influence coffee production and their connections with prices, climate, and investment. Finally, this research utilized Smart-PLS to test the hypotheses regarding the relationships between constructs. Future investigations might incorporate other methodologies, such as covariance-based SEM or multi-group analysis, to validate these findings. Qualitative research tools like interviews or case studies could also provide deeper insights into the challenges faced by coffee farmers concerning climate change vulnerability and financial access. In summary, while this study contributes significantly to understanding the factors affecting coffee production, future research could expand on these findings by incorporating additional variables, exploring wider geographic areas, and employing diverse research methodologies to enhance the understanding of coffee production dynamics.

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