KnE Social Sciences

The 1st International Conference on Creative Design, Business and Society (1st ICCDBS) 2023

KnE Publishing

Research Article

The Impact of Smart Farming Technology on Agricultural Productivity: Evidence from a Large-scale Database in Thailand

Bang-Ning Hwang, Siriprapha Jitanugoon*, and Pittinun Puntha

Department and Graduate Institute of Business Administration, National Yunlin University of Science and Technology, Taiwan

ORCID

Siriprapha Jitanugoon: https://orcid.org/0000-0001-6764-6779

Abstract.

Thailand 4.0 is a national strategy focused on integrating digital technologies and innovation to drive economic development in Thailand. The agricultural sector, a vital part of the economy, plays a crucial role in this strategy. One key initiative is the smart farming project, which aims to enhance agricultural productivity. This study aims to examine the impact of Thailand's smart farming project on agricultural productivity within the context of this policy. In pursuit of this objective, the study adopts a quantitative research methodology, employing a comprehensive analysis of secondary data. The data utilized in the study is obtained from reliable sources, namely the Office of the National Economic and Social Development Council and the FAOSTAT database. This dataset spans the period from 2006 to 2020 and undergoes meticulous analysis through the application of a specified equation. The study findings demonstrate that higher growth rates of total output relative to total inputs result in noticeable improvements in agricultural total factor productivity. This positive outcome can be attributed to the significant influence exerted by Thailand 4.0 and smart farming policies. Consequently, the adoption of smart farming practices in Thailand leads to significant advancements in agricultural productivity. Based on these results, the study provides valuable insights into the implications of Thailand 4.0 for agricultural development and offers recommendations for policymakers and stakeholders. These recommendations involve strategies to leverage digital technologies in agriculture, promote innovation, enhance digital literacy and skills among farmers, and address challenges that hinder the effective implementation of digital transformation initiatives.

Keywords: Thailand 4.0 policy, smart framing, agricultural total factor productivity, innovation, sustainable development

Corresponding Author: Siriprapha Jitanugoon; email: siripraphа.jitanugoon@gmail.com

Published: 19 November 2024

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the 1st ICCDBS Conference Committee.

1. Introduction

The agricultural sector in Thailand has long been a vital pillar of the nation's economic growth. Rooted in the country's history dating back to the Kingdom of Sukhothai, it has undergone substantial modernization and technological advancements. Encompassing diverse activities from traditional rice farming to high-value crop cultivation, as well as thriving livestock and fisheries industries, the sector occupies over 50% of the nation's land, making it a driving force behind Thailand's economic progress [1].

Geographically, Thailand's agricultural significance varies. The central region, famously known as the "rice bowl," with its fertile plains, has solidified Thailand's position as one of the world's top rice producers [2]. Meanwhile, the northeast region has diversified into crops like sugarcane, cassava, and maize, expanding the sector beyond rice. In the north, cooler climates have given rise to specialty crops, such as coffee, creating niche markets [3]. The southern region's unique climate and geography have spurred the production of fruits, rubber, and oil palm, further broadening the country's agricultural portfolio [4]. Although the agricultural sector's contribution to Thailand's Gross Domestic Product (GDP) remains relatively modest compared to other sectors [5], it serves as a crucial safety net due to the country's abundant natural resources and diverse farming and fishing activities. This resilience becomes particularly significant during times of crisis.

In line with Thailand's ambitious Thailand 4.0 development initiatives, the Ministry of Agriculture and Cooperatives (MOAC) launched the Smart Farmer Development Project in 2013. This forward-thinking initiative aims to empower the nation's farmers by equipping them with the skills and knowledge required to thrive in a rapidly evolving agricultural landscape [6]. It harnesses cutting-edge technologies, such as big data analytics, the Internet of Things (IoT), drones, and smartphone applications, to revolutionize farming practices. By optimizing resource utilization, the project seeks to maximize agricultural yields while minimizing the consumption of vital resources like water and fertilizers [7]. Beyond improving agricultural practices, the project also bolsters climate change resilience, enabling farmers to effectively respond to challenges like drought and flooding [8].

Smart farming, as promoted by this project, extends beyond enhancing agricultural productivity; it addresses broader societal issues. It contributes to economic and social equity by increasing income and employment opportunities, particularly in rural areas. It fosters social cohesion and ensures food security, a crucial aspect of any nation's well-being. Existing research has highlighted the potential benefits of smart farming initiatives in various contexts. For instance, Sikora et al. emphasized the role of technology in optimizing resource use [9], while Abegunde et al. highlighted the project's broader impact on climate change awareness and resilience [10]. Similarly, Cameron et al., Newell et al., and Huyer et al. have provided valuable insights into the socioeconomic implications of such projects [11-13]. These studies collectively underscore the significance of smart farming in fostering sustainable agricultural development and rural progress.

Despite a substantial body of literature on the potential benefits of smart farming initiatives, there is a critical gap in empirical research regarding the specific effectiveness and outcomes of Thailand's Smart Farmer Development Project. Our research aims to bridge this gap by empirically investigating the project's impact on agricultural productivity, offering valuable insights and recommendations to enhance its effectiveness. Additionally, our study seeks to connect this initiative to earlier research, providing practical insights and real-world implications of technological advancements in the agricultural sector. Our study provides empirical evidence that the adoption of smart farming practices has significantly elevated agricultural total factor productivity, closely aligning with Thailand 4.0 and related policies, emphasizing the initiative's compatibility with the nation's broader economic development goals.

In the following sections, we will delve deeper into the existing literature, providing a comprehensive overview of relevant research in the field. We will then outline our research methodology, including data sources and analytical techniques. Subsequently, we will present the findings of our study on the determinants of agricultural productivity. Finally, we will conclude our paper by summarizing our key findings and encouraging further discussion and exploration. Our research endeavors to contribute to informed decision-making and the adoption of effective strategies to maximize agricultural productivity, improve the livelihoods of farmers, and promote sustainable agricultural development, not only in Thailand but also as a model for other regions seeking to harness the potential of smart farming.

2. Literature Review

2.1. Smart Framing Thailand

In recent years, Thailand has experienced a notable shift from traditional agricultural practices to industrial agriculture, largely driven by the smart farming project initiated by the Ministry of Agriculture and Cooperatives (MOAC) in 2013. Aligned with the Thailand 4.0 policy, this project emphasizes the integration of cutting-edge technologies and aims to strengthen connections within the agricultural sector [14]. The implementation of precision farming and resource management optimization, facilitated by technological advancements, has gained significant traction in Thailand [15]. By harnessing data-driven decision-making, farmers have achieved higher crop yields while reducing inputs like water, fertilizer, and pesticides, establishing a more sustainable and efficient approach to agriculture. This transition towards industrial agriculture not only promotes sustainable farming practices but also fosters a harmonious relationship between technology and the environment, minimizing environmental impacts and enhancing resource efficiency [16] . The integration of machinery from international suppliers has played a pivotal role in incorporating advanced technologies into local farming practices, resulting in enhanced productivity, improved product quality, and increased crop yields [16]. This amalgamation of technology has empowered Thai farmers to optimize their operations and overcome traditional challenges associated with agricultural practices. Precision farming techniques, including variable rate application of inputs, remote sensing, and real-time monitoring systems, have empowered farmers to make informed decisions based on accurate data, leading to improved resource utilization and increased productivity [17].

Recognizing the enduring importance of agricultural sustainability, the Department of Agricultural Extension (DOAE) in Thailand launched the Young Smart Farmer Program in 2014. This program aims to nurture a new generation of agriculturists who can maximize productivity by leveraging technological advancements. It addresses the critical need to replace over 50 percent of retired farmers with young individuals who possess creativity, innovation, and technological proficiency [18]. By integrating innovative Internet of Things (IoT) systems and enhancing commercial aspects such as production capacity, management, and farm marketing, these young farmers are well-prepared to assume leadership roles in their communities. The establishment of networks comprising smart farmers, smart groups, and smart enterprises encourages knowledge exchange, fosters collaboration, and promotes innovation within the agricultural sector, facilitating continued progress [19-22].

In a broader context, the smart farming project in Thailand holds immense potential to shape the future trajectory of the country's agricultural sector by fostering stronger connections and interdependence. Through the strategic integration of advanced technologies, implementation of sustainable practices, and cultivation of a skilled farming workforce with technological expertise, this initiative establishes the foundation for a more efficient, productive, and sustainable agricultural landscape in Thailand. The utilization of IoT systems and other technological advancements enables farmers to optimize various aspects of their operations, resulting in increased productivity, improved resource management, and enhanced profitability. Furthermore, the establishment of networks among smart farmers, smart groups, and smart enterprises encourages collaboration and knowledge exchange, driving innovation and progress in the agricultural sector. By embracing this comprehensive and interconnected approach, Thailand's agricultural sector can not only address current challenges but also seize opportunities for future growth and resilience, creating a sustainable agricultural future.

2.2. Factors Influencing Agricultural Productivity Growth

Scholars have extensively researched the factors that contribute to the progress of agricultural productivity. Various research studies have explored different determinants that impact agricultural productivity, providing valuable insights into the field [23-27]. This literature review aims to provide an overview of the key factors that influence agricultural productivity growth.

Land availability, quality, and management practices are crucial contributors to agricultural productivity. Improving arable land, enhancing irrigation techniques, and adopting sustainable land use practices have the potential to increase agricultural productivity [28-30].

Labor also plays a significant role, with both the quantity and quality of labor impacting productivity levels. Technological advancements, such as the integration of machinery and automation, have shown their ability to enhance labour productivity [31]. Additionally, investments in human capital through tailored educational and training programs for farmers and agricultural workers have been associated with increased productivity [32].

Access to water resources is crucial, particularly in arid and semi-arid regions. Providing adequate and reliable water supplies for irrigation purposes has a substantial potential to increase crop yields and overall productivity [33] (Hussain et al., 2019). Implementing efficient water management practices, such as drip irrigation and water recycling, has demonstrated the ability to optimize water utilization and enhance agricultural productivity [34].

Fertilizer application and nutrient management are critical factors influencing agricultural productivity growth. Balanced and timely utilization of fertilizers has the potential to replenish soil nutrients and increase crop yields [35]. Moreover, incorporating sustainable nutrient management practices, such as organic fertilizers and crop rotation, can contribute to long-term productivity gains by preserving soil fertility [36].

Technological advancements and agricultural innovation have transformative potential in increasing productivity levels. Adopting improved crop varieties, implementing mechanization and precision farming techniques, and utilizing agricultural biotechnology have yielded significant gains in productivity across diverse regions [37,38]. Purposeful investments in research and development, extension services, and knowledge dissemination emerge as critical components for nurturing technological progress and facilitating subsequent impacts on agricultural productivity.

Infrastructure development, including rural roads, storage facilities, and market access, emerges as a pivotal factor influencing agricultural productivity. Efficient transportation networks and market accessibility facilitate the timely and cost-effective movement of agricultural inputs and outputs, mitigating post-harvest losses and bolstering farmers' profitability [39].

Political stability and supportive policy environments are fundamental prerequisites for agricultural productivity growth. Stable political conditions encourage investments in agriculture and create a conducive business environment, fostering long-term planning and policy continuity [40]. Effective agricultural policies, including appropriate pricing mechanisms, subsidies, and incentives, play a crucial role in incentivizing farmers to adopt modern technologies, enhancing resource allocation efficiency, and elevating overall productivity levels [41].

In summary, agricultural productivity growth is influenced by a multitude of interconnected factors. While traditional inputs like land, labour, water, and capital remain significant, other critical factors include sustainable natural resource management, technological advancements, human capital development, infrastructure, and political stability. Understanding the intricate interplay among these factors and devising comprehensive policies and strategies to address them is paramount in fostering sustained growth in agricultural productivity, ensuring both food security and economic development within the agricultural sector.

2.3. The Solow Residual: Technology's Role in Agricultural Productivity

The Solow Residual, stemming from Robert Solow's groundbreaking work in the 1950s, is a vital tool for analyzing and quantifying total factor productivity (TFP) in agriculture, establishing important connections between economic factors. The Solow Growth Model, which considers labor, capital, and technology, provides valuable insights into economic growth by examining their intricate relationships. Solow's influential study in 1957 identified TFP as the unexplained component of economic growth, attributed to technological innovation, highlighting the fundamental role of technology in driving progress. Subsequent studies have further supported and expanded upon Solow's findings, deepening our understanding of the complex relationship between the Solow Residual and economic productivity [42-44].

By utilizing the Solow Residual, researchers can investigate technology adoption and its impact on TFP in agriculture, shedding light on the dynamic relationship between technological progress and agricultural productivity. For example, Wicki conducted an analysis on the impact of advanced technologies on TFP in a specific region, demonstrating a positive relationship between the two [45]. Moghaddasi and Pour examined the determinants of technology adoption and their influence on TFP, identifying critical factors that shape outcomes [46]. Similarly, studies by Ruzzante et al. have explored the relationship between technology adoption and agricultural productivity, emphasizing the various influencing factors at play [47]. In another study, Chen investigated the effects of mechanization and improved crop varieties on TFP, highlighting the significance of technology adoption for overall productivity [48].

In conclusion, empirical studies that leverage the Solow Residual are crucial for understanding the determinants of technology adoption and its implications for TFP in agriculture. These studies contribute to our knowledge of the intricate interplay between technological advancements, technology adoption, and agricultural productivity, providing a robust analytical framework to explore the multifaceted relationships among these factors. The Solow Residual offers a valuable tool for researchers to quantify the contribution of technology to agricultural productivity growth and inform policy decisions aimed at fostering technological innovation and sustainable agricultural development.

2.4. Institutional Theory: Role in Agricultural Technology Adoption

Institutional Theory, as Eastwood et al. highlights, has emerged as a prominent analytical framework that offers insights into the intricate dynamics of technology adoption in agriculture [49]. This theoretical perspective posits that institutions, encompassing both formal and informal systems of rules, norms, and regulations, exert a significant influence over the decision-making processes of farmers as they navigate the complex terrain of integrating agricultural technologies [50]. Institutional Theory draws on the foundational contributions of scholars like Douglass C. North, a Nobel laureate whose seminal work laid the groundwork for this theoretical framework.

North's conceptualization of institutions emphasizes the presence of both formal and informal constraints that shape human interactions and individual behaviors within specific societal and contextual settings [51]. Formal institutions, as described by Fuentelsaz et al., comprise the legally codified rules and regulations established by governmental bodies [52]. These encompass a spectrum of policies and laws that wield direct influence over various aspects of agriculture, including land tenure, property rights, and access to credit. In contrast, informal institutions represent the unwritten rules, customs, and norms that govern conduct within communities or social groups, exerting a substantial impact on trust, cooperation, and knowledge exchange among farmers [53].

Agriculture is inherently intertwined with institutions operating at different levels, from the local to the national context, underlining the importance of Institutional Theory in comprehending the multifaceted nature of technology adoption within the agricultural sector. The choices made by farmers to embrace new technologies are shaped by the intricate interplay of various institutional factors, underscoring the need for a comprehensive examination of the dynamic relationships between formal and informal institutions. Government policies play a central role in shaping the landscape of agricultural technology adoption, as noted by Bhatt & Singh [54]. Policies governing aspects such as land rights, subsidies, and research and development funding exert direct influence over farmers' access to and motivation for adopting new technologies. This influence is particularly pronounced in developing nations where agriculture often forms the economic backbone, making policies instrumental in configuring the incentives and constraints faced by farmers.

Extension services, typically administered by governmental agencies or non-governmental organizations, serve as crucial conduits for disseminating information about emerging agricultural technologies to farmers. The effectiveness of these services depends on various institutional factors, including funding, training, and the ability to customize information to suit the specific conditions of the local context. Regulations overseeing the quality and safety of agricultural products hold substantial sway over technology adoption in agriculture. These regulatory frameworks have the potential to influence the utilization of specific inputs or practices, thereby shaping farmers' choices [55].

Informal institutions, encompassing community norms and social capital, play a pivotal role in determining the trajectory of technology adoption. The dynamics of social networks, trust, and local customs influence the dissemination of information and the adoption of practices within a community. The presence and effectiveness of farmer organizations are significant factors influencing technology adoption [56]. These organizations frequently serve as intermediaries between individual farmers and governmental agencies, offering platforms for collective decision-making, knowledge sharing, and advocacy in support of policies that enhance technology adoption [57].

In conclusion, striking a balance between the interests of formal and informal institutions, regulatory frameworks, and community dynamics is crucial for creating an environment in which farmers are motivated and empowered to embrace new technologies. Institutional Theory provides a valuable framework for policymakers and researchers as they seek to design strategies that facilitate the sustainable integration of technology into agriculture, ultimately enhancing the productivity and sustainability of this critical sector.

2.5. Total Factor Productivity in Agriculture (TFP)

Total Factor Productivity (TFP) plays a crucial role in assessing economic efficiency by capturing the overall productivity of all inputs in production, enabling higher output levels with the same inputs and facilitating economic expansion. Researchers employ various models and approaches to compute TFP, offering different perspectives on agricultural productivity analysis. The growth accounting model, introduced by Diewert, combines detailed financial records into input and output indices, providing a comprehensive analysis of the factors contributing to productivity changes over time [58].

Numerous studies have explored TFP to understand the factors influencing agricultural productivity. For instance, Key investigates TFP in different-sized grain-producing farms in the U.S. Heartland region from 1982 to 2012, attributing productivity growth to structural changes rather than technological advancements [59]. This highlights the importance of considering the interplay between various factors. Similarly, Moghaddasi and Pour examine the relationship between labor, capital, energy, and agricultural TFP in Iran from 1974 to 2012, revealing the varying impacts of these inputs on TFP growth [45]. These studies underscore the need to consider multiple input factors to comprehensively comprehend TFP dynamics and formulate policies for enhanced agricultural productivity.

In the context of China's agricultural sector, Gong's study of TFP growth from 1978 to 2015 and emphasize the crucial role of technological progress as the primary source of productivity growth [60]. They also observe regional disparities attributed to variations in technological progress across different regions. Similarly, Andersen et al. investigate total factor productivity in American agriculture between 1948 and 2015 and find productivity to be the main driver of sectoral growth, highlighting the instrumental role of innovation and modern technology [61]. These findings emphasize the interconnectedness of technological progress, innovation, and efficient input allocation in driving agricultural productivity.

Overall, literature underscores productivity as a key determinant of agricultural growth, influenced by technological progress, innovation, and the efficient allocation of inputs. Diverse methodologies and empirical studies across countries highlight the contextual nature of agricultural productivity, necessitating tailored approaches to enhance TFP in different regions and time periods. By considering the relationships among these factors, policymakers can develop targeted strategies to optimize agricultural productivity and promote sustainable economic growth.

2.6. Overview of Prior Research

The prior research conducted in the field of smart farming has yielded a comprehensive and interconnected body of knowledge. These studies collectively paint a picture of the evolution, challenges, and immense potential of smart farming technologies in the agricultural sector, setting the stage for the current study, "The Impact of Smart Farming Technology on Agricultural Productivity: Evidence from a Large-Scale Database in Thailand."

The work of O'Grady & O'Hare laid the foundational groundwork by examining models within the farming enterprise and reviewing the state-of-the-art smart technologies [62]. Their study introduced the concept of enterprise-specific models, which could serve as a cornerstone for the emergence of future smart farming enterprises. Pivoto et al. followed with a global perspective, undertaking a dual-purpose mission [63]. First, they characterized the worldwide scientific knowledge on sustainable farming (SF) and identified key developmental factors, both temporally and geographically. Secondly, they delved into the current prospects of SF in Brazil, backed by insights from market and research experts, and bibliometric surveys, thereby providing a rich tapestry of insights into the global and regional dimensions of smart farming.

Raja & Vyas continued to bridge the gap by investigating the diverse technological advancements in smart farming, including the Internet of Things (IoT), wireless communication, irrigation systems, and agricultural automation [64]. Their aim was to furnish emerging researchers in the field with a comprehensive understanding of the current technological progress in smart farming. Virk et al. shed light on the challenges faced by the smart farming domain, notably high implementation costs, limited internet access, and the lack of application knowledge among farmers [65]. They also emphasized notable gaps in the application of autonomous vehicles and drones, calling for further exploration and solutions. Navarro et al. carried the torch further by conducting a systematic review of IoT solutions for smart farming [66]. Their work was instrumental in discerning the principal devices, platforms, network protocols, and data processing technologies used in smart farming. The review highlighted a significant shift from traditional, reactive data usage to a proactive approach, which greatly improved crop diagnostics and issue mitigation.

In the more recent studies, Mohamed et al. dived into the practical applications of smart farming, exploring processes involving data collection, transmission, storage, and analysis [67]. They also investigated the versatile use of unmanned aerial vehicles (UAVs) and robots, showcasing their capabilities in various agricultural tasks. Moysiadis et al. provided a dual-purpose contribution by first offering a comprehensive reference on European research endeavors in the realm of smart farming [68]. This included an in-depth examination of innovative technological trends across various crop sectors. Additionally, the study analyzed the most prominent smart farming projects in Europe, providing a broad view of the European landscape in this field.

The culmination of this extensive body of prior research is the present study, "The Impact of Smart Farming Technology on Agricultural Productivity: Evidence from a Large-Scale Database in Thailand." Building upon the foundations set by the previous studies, this research investigates the tangible effects of smart farming on agricultural productivity in Thailand. It offers empirical evidence of how the integration of smart farming practices, influenced by Thailand 4.0 and smart farming policies, has led to remarkable enhancements in agricultural total factor productivity. This study is intricately linked to the prior research, demonstrating the practical implications of the technological advancements and insights gained from the earlier studies. For a comprehensive overview of previous studies related to smart farming, please consult Table 1.

TABLE 1: Review of previous studies on smart farming.

Authors (Year)	Topic	Study focus
O'Grady & O'Hare (2017)	Modelling the smart farm	In-depth exploration of farming enterprise models and smart technology integration.
Pivoto et al. (2018)	Scientific development of smart farming technologies and their application in Brazil	Characterizing global sustainable farming knowledge and prospects in Brazil through interviews and bibliometrics.
Raja & Vyas (2019)	The Study of Technological Development in the Field of Smart Farming	Examines IoT, wireless communication, and agricultural automation for researchers.
Virk et al. (2020)	Smart Farming: An Overview	Focuses on adoption and transformation of smart farming, enhancing application knowledge, and autonomous vehicles.
Navarro et al. (2020)	A Systematic Review of IoT Solutions for Smart Farming	Reviews IoT devices, data processing, and precision in crop diagnoses.
Mohamed et al. (2021)	Smart farming for improving agricultural management	Details data processes, UAVs, and robots in smart farming from 2019 to 2021.
Moysiadis et al. (2021)	Smart Farming in Europe	Examines European research and prominent projects in Smart Farming.
Current study	The Impact of Smart Farming Technology on Agricultural Productivity: Evidence from a Large-Scale Database in Thailand	Quantitative analysis of Thailand's smart farming impact on agricultural productivity using reliable data sources.

2.7. Conceptual Model

The proposed theoretical model, designed to shed light on these perspectives, is illustrated in Figure 1.

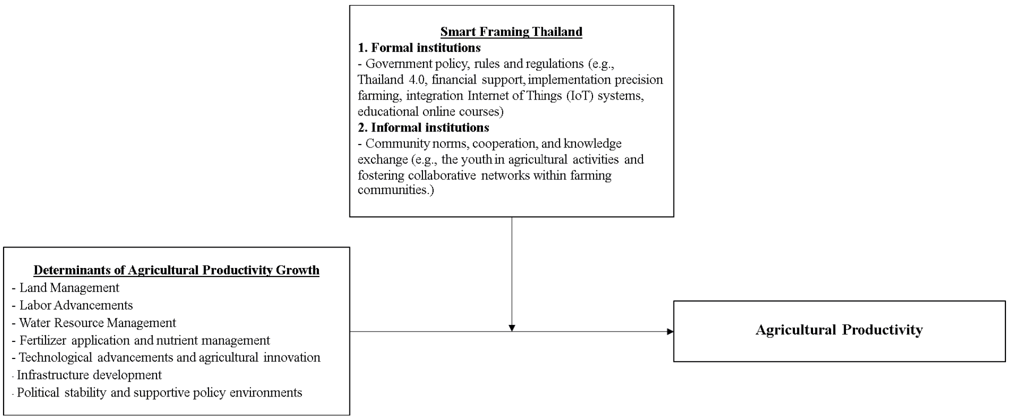

Figure 1: Conceptual model.

3. Methodology Research

3.1. Data

The empirical investigation in this study utilizes an extensive dataset that covers the period from 2006 to 2020. The FAOSTAT database, curated meticulously by the United Nations Food and Agriculture Organization (FAO), serves as the primary data source for obtaining information on production and input quantities. In cases where specific data points are unavailable from national statistics sources, supplementary data from the FAO input and output database is incorporated to ensure comprehensive coverage.

The selection of the time frame for this research, spanning from 2006 to 2020, is justified by two primary reasons. Firstly, it aligns with the establishment of the smart farmer program in Thailand in 2006, which aimed to enhance agricultural practices and improve productivity. Additionally, in 2013, the Ministry of Agriculture and Cooperatives (MOAC) initiated the Smart Farmer Development Project, a significant endeavour that integrated digital online services into the agricultural framework with the participation of approximately 12.6 million farmers. Secondly, the introduction of the useful platform by the MOAC in 2017 proved highly effective in showcasing the latest advancements in "smart farming" facilitated by Internet of Things (IoT) solutions.

These advancements can be classified into two pivotal domains: (1) data-driven farming, involving the integration of big data into on-farm precision agriculture to enhance efficiency through diverse data streams. Farmers gained access to valuable information on temperature control, soil moisture levels, and the implementation of sensors. Data analysis techniques and cloud-based intelligence were utilized to optimize farming practices and improve decision-making. (2) Educational online courses were adopted to empower farmers by enhancing their knowledge and skills in managing agricultural products. These courses focused on online marketing channels, strengthening networks among farmers, and proficiency in utilizing internet applications on mobile devices. By facilitating knowledge transfer and providing increased access to information channels, these courses enabled farmers to improve productivity and stay updated with technological advancements in the agricultural sector.

By integrating data sourced from the FAOSTAT database and conducting a meticulous examination of the chronological framework that underpins the smart farmer program and policy, this selected time span holds the potential to provide a comprehensive understanding of the transformations and advancements that have occurred within Thailand's agricultural sector during the analysed duration.

3.2. Measurement

The aim of this research is to examine the long-term effects of smart farming on agricultural productivity in Thailand. In line with previous work by Fuglie [69], the study employs Total Factor Productivity (TFP) as a comprehensive metric for evaluating agricultural productivity. TFP compares the overall output of crops and livestock to the combined inputs of land, labor, capital, and materials utilized in agricultural production. When the growth rate of total output exceeds that of total inputs, it indicates an improvement in overall productivity. The calculation of TFP is derived from Equation (1):

$$TFP=\frac{Y}{X}(1)$$

In Equation (1), Y represents the total output, while X represents the total input.

Defining meaningful measures of actual output and input in the context of diverse outputs and inputs can be a complex task. However, index number theory provides a framework for establishing suitable definitions of output and input growth between specific time periods. Changes in Total Factor Productivity (TFP) can be assessed by comparing the rate of change in total output with the rate of change in total input over time. These changes, represented as logarithms in Equation (1), are integrated into Equation (2):

$$\frac{d\ ln(TFP)}{dt}=\frac{dln(Y)}{dt}-\frac{dln(x)}{dt}(2)$$

Equation (2) determines the rate of change in Total Factor Productivity (TFP) as the disparity between the rates of change in aggregate output and input.

In the agricultural sector, Y and X are vectors due to the involvement of multiple outputs and inputs in the manufacturing process. Under the assumption of constant returns-to-scale production function, producers strive to maximize profits by equating the elasticity of output with respect to an input to the cost share of that input. This condition enables the achievement of a long-term competitive equilibrium where total revenue equals total cost. Consequently, Equation (2) can be incorporated into Equation (3):

$$ln\frac{TFP_t}{TFP_{t-1}} = \sum_i R_i ln\frac{Y_{i,t}}{Y_{i,t-1}} - \sum_i S_i ln\frac{X_{i,t}}{X_{i,t-1}} \quad (3)$$

In Equation (3), R_i denotes the revenue share of the ith output, while S_j represents the cost share of the jth input. The growth of total output is calculated by averaging the growth rates of each output commodity, taking into account their respective revenue shares. Similarly, the growth of total input is computed by summing the growth rates of each input, considering their cost shares as weights. TFP growth is simply the difference between the growth of total output and total input. A significant limitation in utilizing equation (3) to measure agricultural productivity change arises from the lack of comprehensive cost share data available for most countries. Therefore, equation (4) provides an alternative approach by incorporating $g(Z)$ to represent the annual growth rate of a variable. In this formulation, the growth in output consists of the growth in TFP plus the growth rates of inputs multiplied by their respective cost shares:

$$g(Y) = g(TFP) + \sum_{j=1}^{J} S_j g(X_j)(4)$$

Equation (4) serves as a cost decomposition of output growth, as each term $S_j g(X_j)$ captures the growth in cost resulting from the increased utilization of the jth input to enhance output. Another aspect to consider is the analysis of a specific input, such as land (designated as X_i), allowing for the decomposition of growth into the contributions arising from resource expansion and the yield of that resource:

$$g(Y) = g\left(X_1\right) + g\frac{Y}{X_1}(5)$$

This decomposition corresponds to the commonly known concepts of extensification (land expansion) and intensification (land yield growth). Furthermore, it is possible to further decompose yield growth into the share attributed to TFP and the share attributed to the increased intensity of other inputs per unit of land:

$$g(Y) = g\left(X_1\right) + g(TFP) + \sum_{j=2}^{J} S_j g\frac{X_j}{X_1}(6)$$

Equation (6) represents a resource decomposition of growth, as it focuses on the quantitative changes of a physical resource (land) rather than its impact on production costs.

Figure 2 presents a graphical depiction of the growth decomposition outlined in equation (6). The illustrate the agriculture productivity. Initially, the growth in real agriculture productivity is partitioned into two components: extensification, which pertains to the expansion of agricultural land, and intensification, which relates to the increase in yield per hectare. Furthermore, the growth in yield itself undergoes additional decomposition into two factors: input intensification, which is characterized by the augmentation of capital, labor, and fertilizer utilization per hectare of land, and TFP growth. Total Factor Productivity (TFP) serves as a metric for assessing the efficiency with which all inputs are transformed into outputs. Enhancements in TFP are influenced by diverse factors, including technological advancements, improvements in technical and allocative efficiency in resource allocation, and economies of scale within agricultural practices.

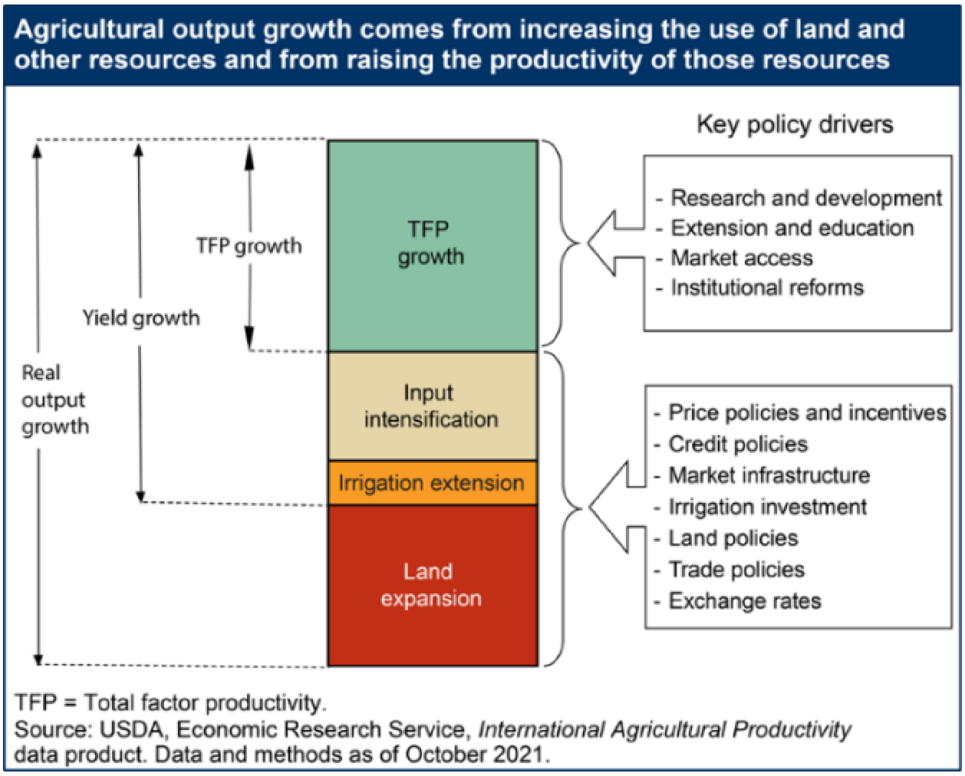

Figure 2: Growth in Output, Yield and TFP.

4. Result and Discussion

This research endeavour focuses on exploring the impact of smart farming project on agricultural productivity in Thailand, specifically examining their influence on augmenting productivity levels. The study presents the outcomes in Table 2, which provides a condensed overview of productivity metrics related to the Thai agricultural sector from 2006 to 2020. The table's initial columns display aggregated data on agricultural inputs and outputs, while the subsequent columns present numerical values for four specific productivity measures: Total Factor Productivity (TFP), Area Harvested, Yield per hectare harvested, and Production (in metric tons).

During the analysed timeframe, both total input and total output values exhibit fluctuations. In 2006, the total input was 92 units, slightly lower than the total output of 89 units. Subsequent years show variations in both total input and total output. From 2007 to 2010, there is a gradual increase in both values, with a peak of 105 units reached in 2011. This positive trend indicates effective translation of input investments into output gains, suggesting improved agricultural productivity during this period. Between 2012 and 2015, there is a relatively stable period with minor fluctuations in total input and total output. The values remain close to each other, indicating a balance between input and output levels during this time frame. Starting from 2016, there is a slight increase in both total input and total output. However, in 2020, the total output decreases to 101 units, while the total input remains relatively steady at 103 units. This decline in output suggests a potential decrease in productivity during the final year of the analysed period.

The dataset on Total Factor Productivity (TFP) in Thailand's agricultural sector from 2006 to 2020 offers valuable insights into the sector's efficiency and overall productivity, revealing notable patterns and trends. From 2006 to 2013, the TFP shows relatively limited fluctuations, ranging from 97 to 104. This indicates a moderate degree of variability in agricultural productivity over this timeframe. Subsequent examination of the data reveals a gradual but discernible upward trajectory in TFP, peaking at 106 between 2017 and 2019. This period signifies a significant phase characterized by substantial enhancements in agricultural productivity and efficiency. However, in 2020, there is a noticeable deviation from the upward trend, as evidenced by a conspicuous decline in TFP to 98. This decline can be attributed to a severe drought, which had profound repercussions on agricultural production. The Ministry of Agriculture and Cooperatives reports substantial losses estimated at around 26 billion Thai Baht (approximately U.S.

$840 million) in agricultural output due to the adverse effects of the drought. Hence, the impact of the drought emerges as a key contributing factor to the observed decline in TFP during that year.

The data also reveals distinct trends and patterns in the variables of area harvested, yield, and production, shedding light on the overall performance and productivity of the sector during the specified time frame. The findings indicate that the area harvested experiences fluctuations over the studied years but generally remains within a stable range. It gradually increases from 11,342,030 hectares in 2006 to its peak at 13,328,078 hectares in 2010, with minor variations thereafter. This suggests a consistent level of utilization of agricultural land for cultivation. In contrast, the yield demonstrates a consistent upward trajectory with intermittent fluctuations. The average yield per hectare starts at 30,095 hectograms (hg/ha) in 2006 and steadily rises to its highest point of 32,572 hg/ha in 2011. Over the years under analysis, the yield consistently exceeds 30,000 hg/ha, which demonstrates a persistent enhancement in agricultural practices, resulting in elevated productivity and higher crop yields. This consistent performance in agriculture indicates a steady progression and improvement. The production metric, derived from the multiplication of the area harvested by the yield, displays fluctuations while maintaining a general stability. The lowest production output of 32,890,604 tonnes is observed in 2015, while the highest level of 43,447,714 tonnes is recorded in 2011. Throughout the study period, the production output generally ranges between 32 million and 43 million tonnes. These variations in production can be attributed to factors such as weather conditions, technological advancements, and changes in farming practices.

The trends and patterns observed in Table 2 underscore the importance of continuous improvement in agricultural practices for increasing yields and ensuring stable production levels. While total input and output, as well as the area harvested and production, may experience fluctuations over time, the consistent upward trajectory of the yield indicates the successful implementation of agricultural technologies and techniques that contribute to enhanced productivity. Figure 3 provides a comprehensive overview of the trends in Area Harvested, Yield, and Production in the agricultural sector of Thailand from 1961 to 2021. This analysis offers valuable insights into the historical developments, challenges, and opportunities within the sector, facilitating a better understanding of its dynamics and informing policy decisions aimed at enhancing agricultural productivity and sustainability.

TABLE 2: Agricultural Productivity Indicators for Thailand Agriculture from 2006 to 2020.

Years	Total input	Total output	Agricultural TFP	Area Harvested (ha)	Yield (hg/ha)	Production (tones)
2006	92	89	97	11,342,030	30,095	34,133,744
2007	94	97	103	11,875,069	30,894	36,686,811
2008	96	96	100	11,946,683	30,635	36,598,693
2009	97	98	101	12,471,675	29,959	37,363,714
2010	99	98	98	13,328,078	30,713	40,933,902
2011	105	105	99	13,338,804	32,572	43,447,714
2012	111	112	101	13,338,796	32,566	43,438,509
2013	108	107	99	13,080,548	32,140	42,040,227
2014	101	105	104	12,051,561	31,411	37,855,165
2015	100	100	100	11,116,700	29,587	32,890,604
2016	99	103	105	11,990,617	30,588	36,677,356
2017	99	105	106	12,032,106	31,723	38,169,115
2018	103	109	106	12,016,065	31,514	37,866,984
2019	102	106	104	11,126,604	30,211	33,614,125
2020	103	101	98	11,788,948	30,137	35,528,126

Note:
1. Total input, Total output and Agricultural TFP indices (base year 2015=100)
2. Area harvested (ha) refers to the actual area from which harvests are realized, in hectares
3. Yield (hg/ha) refers to the yield in hectograms per hectare
4. Production (tonnes) denotes the total production in metric tonnes.

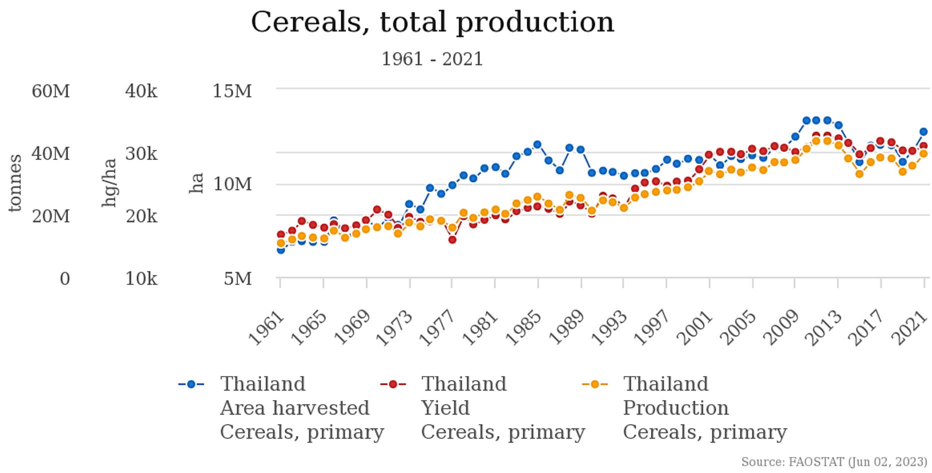

Figure 3: Trends in Agricultural Statistics in Thailand: An Analysis of Area Harvested, Yield, and Production from 1961 to 2021 (FAOSTAT, 2023).

Table 3 provides a comprehensive overview of the growth rates in various aspects of agricultural productivity from 2006 to 2020. The fluctuations observed in the growth rates of these indicators highlight the complex interplay of factors that impact the sector's performance. These factors encompass a wide range of variables, including weather conditions, technological advancements, market dynamics, and policy interventions, all of which contribute to shaping agricultural productivity outcomes.

The total input growth rate captures the pace at which inputs such as labour, capital, and technology are employed in the agricultural sector. The data reveals considerable variability in the total input growth rate, spanning from -6.48% to 6.06% over the analysed period. This signifies fluctuations in the allocation of resources to agriculture, which may result from changes in investment levels, shifts in labour availability, or modifications in technology adoption.

The total output growth rate mirrors the overall expansion of agricultural output. The table exhibits significant fluctuations ranging from -4.76% to 8.99% throughout the studied timeframe. These variations imply changes in agricultural production levels, which could be attributed to shifts in consumer demand, alterations in productivity levels, or the occurrence of natural disasters affecting crop yields.

The agricultural total factor productivity (TFP) growth rate gauges the rate of technological progress and efficiency improvements in the agricultural sector, beyond the contributions of input growth. The presented data unveils fluctuating TFP growth rates, spanning from -5.77% to 6.19%. These fluctuations indicate variations in the sector's ability to enhance productivity through technological advancements, innovation in farming practices, and effective resource management strategies.

The area harvested growth rate elucidates the rate of change in the total land area utilized for agricultural purposes. The recorded values exhibit fluctuations ranging from -7.85% to 7.86%. These oscillations are influenced by factors such as changes in land availability, alterations in land use policies, or shifts in crop rotation practices.

The yield growth rate reflects the rate of change in crop productivity per unit of land. The data showcases varying values ranging from -5.80% to 6.04%. These fluctuations underscore changes in the efficiency and effectiveness of agricultural practices, including advancements in seed varieties, the application of fertilizers, and the utilization of improved irrigation methods.

Production growth rate represents the rate of change in agricultural output resulting from the combined effects of changes in the area harvested and yield. The table demonstrates a wide range of fluctuating values, ranging from -13.12% to 11.51%. These variations indicate shifts in the sector's capacity to produce agricultural goods efficiently and meet the demands of a growing population. Factors influencing production growth rate include changes in land availability, technological advancements, weather conditions, and shifts in agricultural practices.

Table 3: Agricultural Productivity Indicators for Thailand's Agriculture: Annual Growth Rates in Percent.

Years	Total input	Total output	Agricultural TFP	Area Harvested	Yield	Production
2006	2.22%	3.49%	3.19%	-1.16%	-1.22%	-2.37%
2007	2.17%	8.99%	6.19%	4.71%	2.65%	7.47%
2008	2.13%	-1.03%	-2.91%	0.60%	-0.84%	-0.24%
2009	1.04%	2.08%	1.00%	4.40%	-2.20%	2.09%
2010	2.06%	0.00%	-2.97%	6.87%	2.52%	9.54%
2011	6.06%	7.14%	1.02%	0.08%	6.04%	6.14%
2012	5.71%	6.67%	2.02%	0.00%	-0.02%	-0.02%
2013	-2.70%	-4.46%	-1.98%	-1.94%	-1.31%	-3.22%
2014	-6.48%	-1.87%	5.05%	-7.85%	-2.26%	-9.97%
2015	-0.99%	-4.76%	-3.85%	-7.74%	-5.80%	-13.12%
2016	-1.00%	3.00%	5.00%	7.86%	3.39%	11.51%
2017	0.00%	1.94%	0.95%	0.34%	3.71%	4.07%
2018	4.04%	3.81%	0.00%	-0.13%	-0.66%	-0.79%
2019	-0.97%	-2.75%	-1.89%	-7.40%	-3.99%	-11.23%
2020	0.98%	-4.72%	-5.77%	5.95%	-0.24%	5.70%

5. Conclusion

This research study aimed to examine the impact of smart farming projects on agricultural productivity in Thailand, specifically focusing on augmenting productivity levels. The analysis of the data presented in Table 2 and Table 3 provides valuable insights into the trends and patterns observed in various productivity metrics within the Thai agricultural sector from 2006 to 2020.

The findings from Table 2 reveal fluctuations in total input and total output values over the studied period. While there were periods of gradual increase and stability, the final year of analysis showed a decline in total output. The analysis of Total Factor Productivity (TFP) highlights a moderate degree of variability over the years, with a noticeable peak in productivity between 2017 and 2019, followed by a decline in 2020 due to a severe drought. The variables of area harvested, yield, and production demonstrate both fluctuations and consistent improvements over the analyzed timeframe, with advancements in agricultural practices contributing to higher yields and stable production levels.

Table 3 expands on the growth rates of these productivity indicators, providing further insights into the complexities involved in shaping the sector's performance. Fluctuations in total input growth rate reflect changes in resource allocation, while variations in total output growth rate indicate shifts in production levels. The TFP growth rate captures the sector's ability to enhance productivity through technological advancements and efficient resource management. Changes in area harvested growth rate reflect alterations in land availability and usage, while variations in yield growth rate signify shifts in crop productivity. The production growth rate, influenced by multiple factors, represents the sector's capacity to meet the demands of a growing population.

The trends and patterns observed in both tables underscore the importance of continuous improvements in agricultural practices for increasing yields and ensuring stable production levels. The findings suggest that the implementation of smart farming projects has contributed to enhanced productivity and efficiency within the Thai agricultural sector. However, the sector remains vulnerable to external factors such as adverse weather conditions, as evidenced by the decline in TFP in 2020 due to a severe drought. These insights have significant implications for policymakers and stakeholders in the agricultural sector.

5.1. Implication

5.1.1. Theoretical Implication

The theoretical implications of this research transcend existing paradigms in agricultural economics and smart farming, as we delineate their dual nature. Our study contributes to both the affirmation of established theories and the development of innovative theoretical frameworks in this field.

Our research findings underscore the consistent resonance with established theories concerning the symbiotic relationship between technological adoption, specifically smart farming practices, and agricultural productivity. This affirmation resonates with a body of literature that has long emphasized the transformative effects of technology on agricultural efficiency and output. The study reinforces this connection, thereby strengthening the foundation of extant research in the field [70,71].

Moreover, our research outcomes emphasize the enduring relevance of sustainable agricultural practices within the contemporary context of environmental challenges. These implications align seamlessly with prevailing theoretical frameworks that emphasize the critical need for resilience and sustainability in agricultural systems, particularly in light of changing climate patterns. This alignment reinforces the existing knowledge base, further solidifying the importance of sustainability in agricultural economics [72-74].

Moving beyond the affirmation of existing theories, our study also carries the potential to engender novel theoretical perspectives in agricultural resilience. The observed decline in Total Factor Productivity (TFP) in 2020, attributed to a severe drought, has the capacity to catalyze the development of new theories related to agricultural resilience. We highlight the necessity to comprehend how agricultural systems adapt to and recuperate from adverse conditions. This potential development can spawn theoretical frameworks that delve into the dynamic interplay between technology adoption and resilience in agriculture, thereby providing fresh insights into the subject.

Similarly, the research contributes to the establishment of a nascent theoretical framework focused on agricultural innovation. Demonstrating the positive impact of innovative agricultural practices facilitated by smart farming projects, our study lays the groundwork for investigating the factors underpinning innovation in agriculture, its multifaceted impact on productivity, and strategies for its sustained application and scalability across diverse contexts.

Our research also exposes dynamic fluctuations in productivity driven by climate-related factors, exemplified by the 2020 decline in TFP. These observations ignite the potential development of a novel theoretical framework exploring the intricate relationship between technology adoption and climate resilience in agriculture. Such a framework seeks to unravel how technology can either mitigate or exacerbate the impacts of climate change on agricultural productivity, a critical facet in contemporary agricultural economics.

In summary, our research's theoretical implications both affirm existing theories related to technology adoption and sustainability in agriculture and have the potential to foster the inception of novel theoretical frameworks centered on resilience, innovation, and the intricate technology-climate nexus in agricultural systems. This dual contribution enriches the field, yielding a deeper comprehension of the intricate forces shaping agricultural productivity, especially in the context of smart farming initiatives.

5.1.2. Policy Implication

The findings of the research on the impact of smart farming projects in Thailand have significant implications for policymakers aiming to enhance agricultural productivity, efficiency, and sustainability. The data presented in Table 2 and Table 3 offer valuable insights that can guide decision-making processes for policymakers and stakeholders involved in the agricultural sector.

To begin with, the fluctuations observed in total input and total output underscore the importance of effective resource management strategies. Policymakers should prioritize optimizing the allocation of resources such as labor, capital, and technology to ensure their efficient utilization in agricultural production. This can be achieved through targeted investments in agricultural infrastructure, facilitating access to modern technologies, and implementing capacity building programs for farmers. Additionally, the decline in Total Factor Productivity (TFP) in 2020 due to a severe drought highlights the need to address climate resilience in agricultural systems. Policymakers should give priority to measures that mitigate the impacts of climate change. These measures may include promoting climate-smart agricultural practices, improving water management techniques, and investing in drought-resistant crop varieties. Furthermore, policies supporting farmers in adapting to changing climatic conditions and providing insurance schemes to mitigate risks can significantly contribute to enhancing the sector's resilience.

Moreover, the consistent improvements observed in the area harvested, yield, and production over the analyzed timeframe underscore the positive effects of advancements in agricultural practices. Policymakers should actively encourage the adoption of sustainable and innovative farming techniques, such as precision agriculture, efficient irrigation systems, integrated pest management, and soil conservation practices. Supporting farmers with access to information, training, and financial incentives can facilitate the widespread adoption of these practices, leading to increased yields and stable production levels. Furthermore, the growth rates presented in Table 3 highlight the need for comprehensive policies that consider multiple dimensions of agricultural productivity. Policymakers should adopt a holistic approach that not only focuses on input and output growth but also prioritizes improving Total Factor Productivity (TFP) through technological advancements and knowledge transfer. Fostered collaboration between research institutions, extension services, and farmers can play a pivotal role in promoting the adoption of innovative and sustainable farming practices.

To summarize, the policy implications derived from this research emphasize the significance of efficient resource management, climate resilience, and the adoption of innovative farming practices in enhancing agricultural productivity in Thailand. Policymakers should concentrate their efforts on investing in agricultural infrastructure, climate-smart practices, and knowledge transfer to support farmers in improving their productivity and ensuring the long-term sustainability of the agricultural sector. By implementing these policies, Thailand can strengthen its agricultural sector, increase food security, and contribute to sustainable economic development.

5.2. Limitations and Future Research

While the research study presented here offers valuable insights into the impact of smart farming projects on agricultural productivity in Thailand, it is crucial to recognize and address certain limitations that could be expanded upon in future research endeavors.

One limitation to consider is the reliance on aggregated data for measuring productivity. While the data provided in Table 2 and Table 3 give a broad overview of productivity trends, a more detailed analysis at a regional or crop-specific level would provide a deeper understanding of the effects of smart farming projects. Collecting more granular data that captures variations across different agricultural subsectors and regions in Thailand would be beneficial for future research. Furthermore, the analysis in this study is limited to a specific timeframe, spanning from 2006 to 2020. To gain a comprehensive understanding of the long-term impact of smart farming projects, it would be valuable to extend the analysis beyond 2020 and examine the sustained effects of these interventions on agricultural productivity. Conducting longitudinal studies that track changes in productivity metrics over an extended period would yield insights into the durability and effectiveness of smart farming practices.

Moreover, delving deeper into the factors influencing the observed fluctuations in productivity metrics would enhance the research. While the study acknowledges factors such as weather conditions and technological advancements, a more comprehensive analysis of the underlying drivers, including policy interventions, market dynamics, and socio-economic factors, would improve our understanding of the impact of smart farming on productivity. Future research could employ econometric models or qualitative approaches to investigate causal relationships and identify the specific mechanisms through which smart farming projects influence productivity outcomes. Lastly, it is important to note that this research study primarily focuses on the impact of smart farming projects on productivity and does not explicitly consider the economic and environmental implications of these interventions. Future research could incorporate economic analyses to evaluate the cost-effectiveness of smart farming practices and assess their potential for enhancing profitability and sustainability in the agricultural sector. Additionally, conducting environmental assessments would allow for an examination of the resource efficiency and environmental footprint of smart farming technologies and techniques.

In conclusion, while this research provides valuable insights into the impact of smart farming projects on agricultural productivity in Thailand, it is crucial to address the limitations in future studies. By doing so, we can achieve a more nuanced understanding of the relationship between smart farming, productivity outcomes, and sustainability. This will inform policy decisions and interventions in the agricultural sector, leading to more effective and informed approaches to enhance agricultural productivity and sustainability in Thailand.

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