APO PRODUCTIVITY OUTLOOK 2025

The Impacts of Climate Change on Productivity and Its Policy Implications

APO

KDI

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FOREWORD

The impacts of climate change have emerged as one of the most pressing challenges of our time, with profound implications for economies, societies, and ecosystems worldwide. In the Asia-Pacific region, the intersection between climate change and productivity is a critical area of focus, as many areas are vulnerable to the increasing frequency of extreme weather events, temperature fluctuations, and other climate-induced disruptions. This vulnerability calls for a deeper understanding of how climate change will shape future productivity patterns across the region.

This study was undertaken to address the growing need for evidence-based insights into how climate change affects productivity in diverse sectors, including agriculture, manufacturing, and services. As the region faces heightened risks and uncertainties from climate variability, understanding these dynamics is crucial for developing strategies that not only mitigate the adverse effects of climate change but also sustain and enhance productivity growth. By analyzing sector-specific data, this report seeks to inform policy decisions aimed at minimizing disruptions to economic activities.

This research presents a comprehensive analysis of the impacts of climate change on productivity across APO member economies, supported by robust empirical evidence and data-driven models. It explores the nuanced effects of climate variability on key sectors and offers valuable insights into adaptation and mitigation strategies that can be implemented to reduce the negative impacts of climate change. The findings underscore the importance of targeted interventions and collaborative efforts in addressing the complex interplay between climate and productivity.

In collaboration with the Korea Development Institute (KDI), this study has been a valuable joint effort in understanding and addressing the multifaceted impacts of climate change. We hope that the findings and implications of this report will contribute to the shaping of effective climate adaptation and productivity enhancement strategies across APO members in the Asia-Pacific region, supporting long-term economic resilience in the face of a changing climate.

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Secretary-General
Asian Productivity Organization
Tokyo

INTRODUCTION

The APO Productivity Outlook 2025 examines the relationship between productivity and climate change, offering critical insights into how climate variability affects APO member economies. Climate change has emerged as one of the key challenges of the 21st century, with significant implications for productivity across all sectors of the economy. As temperatures rise, weather patterns shift, and extreme events become more frequent, understanding the channels through which climate change affects productivity is crucial for ensuring sustainable development. This edition of the Outlook seeks to address these challenges by examining the multifaceted relationships between climate change and productivity, with an emphasis on sector-specific impacts and evidence-based policy measures.

The objectives of this report are threefold: first, to identify key channels through which climate change affects overall productivity in APO member economies; second, to assess the sector-specific impacts of climate change on agriculture, manufacturing, and services, given the distinct challenges faced by each sector; and third, to formulate evidence-based policy recommendations for adaptation and mitigation strategies, thereby enabling APO member economies to reconcile the dual objectives of enhancing climate resilience and sustaining productivity growth.

The report is organized into four chapters. The opening chapter presents an overview of productivity trends in APO member economies, focusing on labor productivity and TFP. Rising temperatures are estimated to have a statistically significant negative impact on labor productivity, with declines ranging from 2.8% to 8.3% per 1°C increase. Given that average temperatures in APO members increased by 1.13°C between 1970 and 2021, this corresponds to a cumulative reduction in labor productivity of around 3.2% to 9.4%.

The subsequent chapters examine the sector-specific dynamics of climate change, providing a deeper analysis of how its effects vary across agriculture, manufacturing, and services.

In the **agricultural sector**, temperature anomalies significantly hinder productivity, especially in low- and middle-income economies. These economies are particularly vulnerable due to their reliance on climate-sensitive farming practices. To mitigate these impacts, the report recommends strengthening critical adaptation infrastructure, such as enhancing irrigation systems and improving drought management capabilities. Additionally, low-carbon farming techniques and agroforestry are proposed as effective mitigation strategies to reduce environmental impact while sustaining productivity.

In the **manufacturing sector**, the effects of climate change are especially pronounced in lower-middle-income economies, which often lack the infrastructure and resources needed to adapt. The report emphasizes the need for investments in climate-resilient infrastructure, such as heating and cooling systems in production facilities, and the adoption of energy-efficient technologies. Promoting green production systems is also critical to minimize the environmental footprint of manufacturing processes and ensure long-term productivity growth.

Finally, in the **services sector**, temperature changes have nonlinear effects, with temperature-sensitive industries such as tourism and transportation being particularly vulnerable. The report suggests that to maintain competitiveness and ensure operational continuity, businesses must invest in climate-adaptive infrastructure. Additionally, adopting renewable energy technologies and promoting energy efficiency are essential to reduce carbon emissions and enhance resilience in this sector.

By integrating empirical evidence with actionable insights, the *APO Productivity Outlook 2025* provides member economies with the tools to address the dual imperatives of climate resilience and productivity growth.

OVERVIEW OF THE IMPACTS OF CLIMATE CHANGE ON OVERALL PRODUCTIVITY IN APO MEMBER ECONOMIES

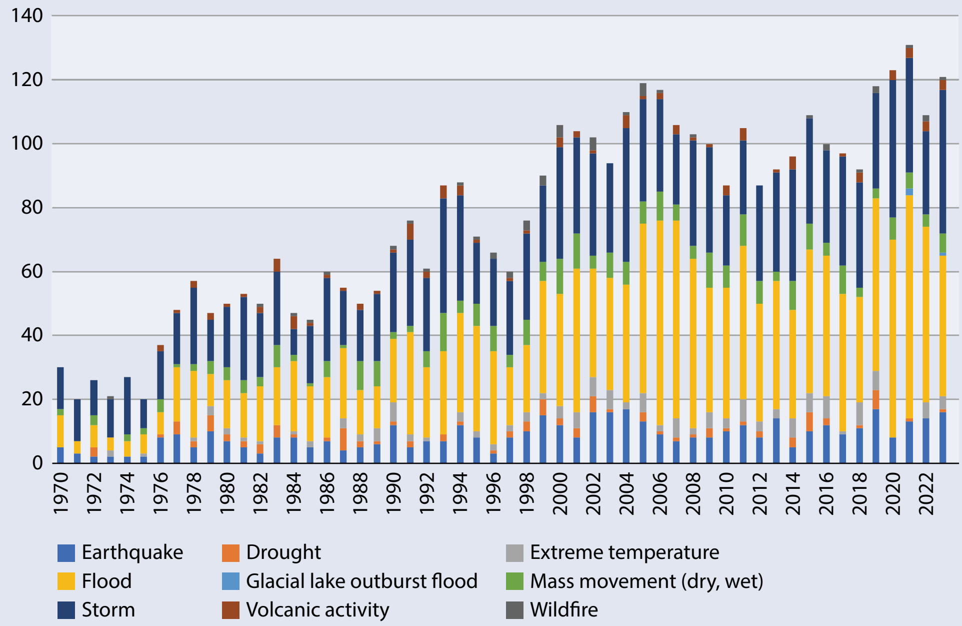
1. Introduction

In an age marked by rapid globalization and the growing threat of climate change, understanding its profound effect on productivity has become ever more crucial. The Intergovernmental Panel on Climate Change Report (2022) underscores the urgency of tackling the escalating climate-related disasters and safeguarding the adaptation and resilience of the most vulnerable. According to the findings of the report "Economic Losses, Poverty, and Disasters", there was a significant increase of 151% in direct economic losses worldwide due to climate-related disasters (UN, 2018). Between 1998 and 2017, countries affected by disasters experienced direct economic losses amounting to USD2,908 trillion, with climate-related disasters contributing USD2,245 trillion, representing 77% of the total.

Climate change manifests through elevated temperatures, ocean acidification, and a rise in global sea levels. Numerous international organizations and multilateral development banks are placing greater emphasis on the economic implications of climate change, acknowledging its progressively intensifying effects over time. To support countries suffering from the aftermath of climate change, the ADB has announced a leveraged guaranteed mechanism for climate finance. This marks a significant milestone in collaboration with multilateral banks to bolster the Asia-Pacific (APAC) countries grappling with climate-related disasters, as the APAC region bears the brunt of over 40% of climate disasters, leading to widespread climate displacement. Moreover, as illustrated in Figure 1, the frequency of nine types of climate-related disasters has been on the rise since 1970 in APO member economies, underscoring the urgency for implementing precise, data-driven guidelines.

FIGURE 1-1

DISASTER TREND BY TYPE IN APO MEMBER ECONOMIES, 1970–2023



Source: Authors' calculation using EM-DAT Database.

Countries highly vulnerable to external shocks and economic volatility are disproportionately affected by natural hazards driven by climate change, a significant challenge for many APO member economies. This vulnerability necessitates a comprehensive understanding of the productivity landscape in these economies to propose effective policy measures for mitigation and adaptation. Therefore, this chapter analyzes productivity trends in APO member economies by examining both labor productivity and TFP, as well as decomposing aggregate labor productivity changes into structural and within-sector components. Building on existing research and empirical evidence, it further explores the relationship between climate change and productivity, aiming to derive actionable policy implications.

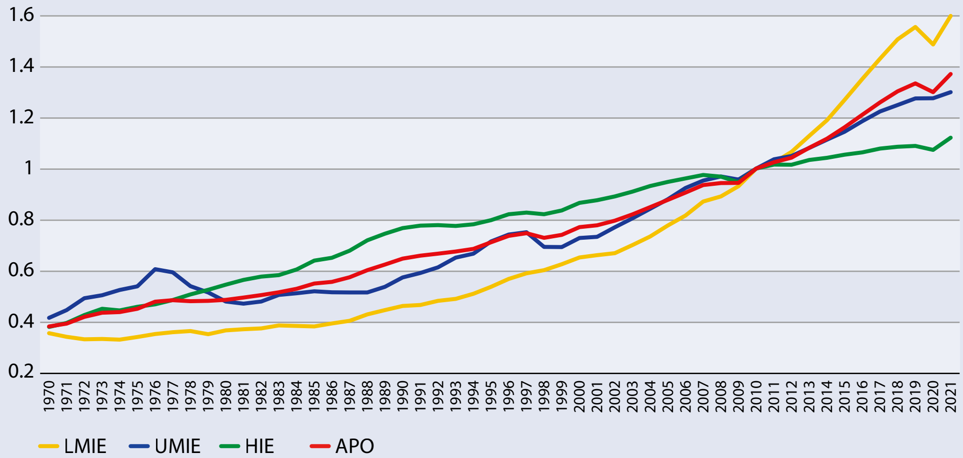
2. Productivity Trends in APO Member Economies

2.1 Overall Productivity

Labor productivity is a critical economic indicator that plays a significant role in driving economic growth. It measures the total output (GDP) produced per unit of labor, quantified by either the number of employed individuals or hours worked over a given period. Figure 1-2 depicts the labor productivity trends of APO member economies, categorized by income level. The most notable increase was observed in low-middle-income economies (LMIE), represented by the yellow dotted line. This group showed significant growth in productivity throughout the period, indicating substantial economic progress. Upper-middle-income economies (UMIE), shown by the blue dashed line, maintained a consistent upward trend; however, their productivity levels remained below the weighted average of APO member economies. High-income economies (HI), represented by the green dashed line, displayed a unique pattern, showing a declining trend over time. The overall weighted average of labor productivity across all APO member economies, represented by the solid red line, showed a steady upward trajectory, reflecting general improvements across the region.

FIGURE 1-2

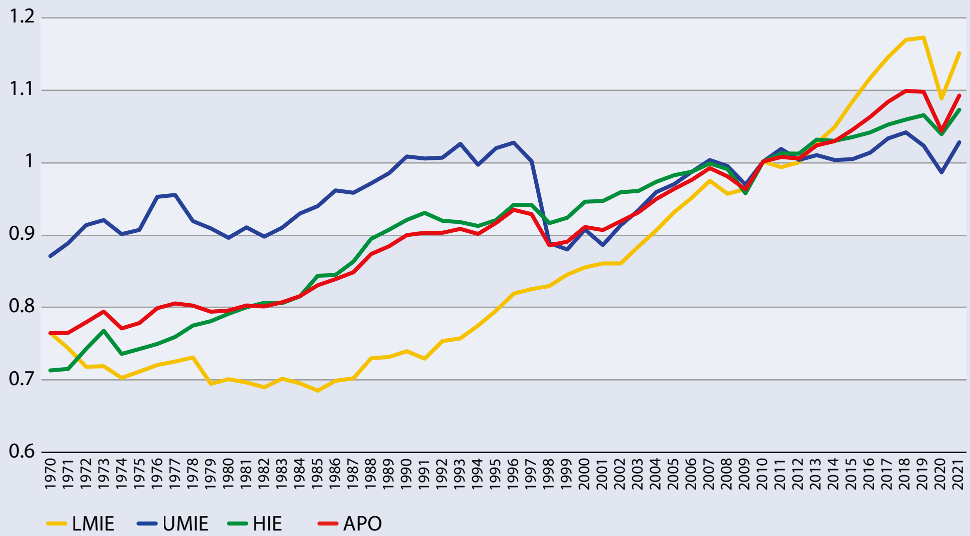
TREND OF LABOR PRODUCTIVITY BY INCOME LEVEL IN APO MEMBER ECONOMIES IN 1970–2021



Note: APO (weighted labor productivity of APO member economies), LMI (low-middle-income economies), UMI (upper-middle-income economies), HI (high-income economies)
Source: Author's calculations based on the APO Productivity Database

FIGURE 1-3

TREND OF TOTAL FACTOR PRODUCTIVITY BY INCOME LEVEL IN APO MEMBER ECONOMIES IN 1970–2021



Note: APO (weighted labor productivity of APO member economies), LMI (low-middle-income economies), UMI (upper-middle-income economies), HI (high-income economies)
Source: Author's calculations based on the APO Productivity Database

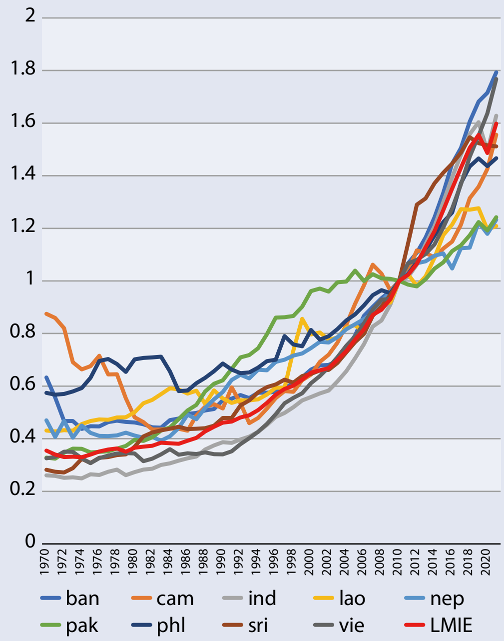
TFP is a key measure of productivity efficiency that evaluates how effectively an economy transforms inputs (such as labor and capital) into outputs, serving as an indicator of overall technological progress and resource utilization. According to data from the APO Database 2023, the overall increase in TFP (from 0.76 to 1.09) was lower than the growth in labor productivity (from 0.38 to 1.37). Despite this slower overall increase, TFP trends exhibited similar patterns across different income groups. The yellow dotted line, representing low-middle-income economies (LMIE), starts at a lower level, but shows significant growth after the 1990s. The blue dashed line, representing upper-middle-income economies (UMIE), maintains the highest TFP level until 1998. High-income economies (HIE), depicted by the green dash-dotted line, demonstrate steady growth, indicating stable progress over the period. Lastly, the solid red line for APO shows a pattern similar to that of HIE.

Both labor productivity and TFP of low-middle-income economies (LMIE) have reached their highest levels since 2012. This outperformance may be explained by Clark Kerr's Convergence Theory. According to Kerr, lower-income countries can achieve faster growth by adopting existing technologies and practices from higher-income countries, thereby bypassing the need to develop these innovations independently. This concept is further supported by the Solow-Swan model, which suggests that economic growth is driven by the accumulation of physical capital until a "steady state" is reached. The model predicts that countries with lower levels of physical capital per capita can grow more rapidly, a phenomenon known as "catch-up" growth.

Although countries within each income classification generally follow similar trends, individual nations exhibit distinct productivity patterns due to their unique social, economic, and political contexts. Therefore, the following sections will examine the productivity trends of each nation within the 21 APO member economies to provide a more comprehensive understanding of these trends within specific national contexts.

FIGURE 1-4

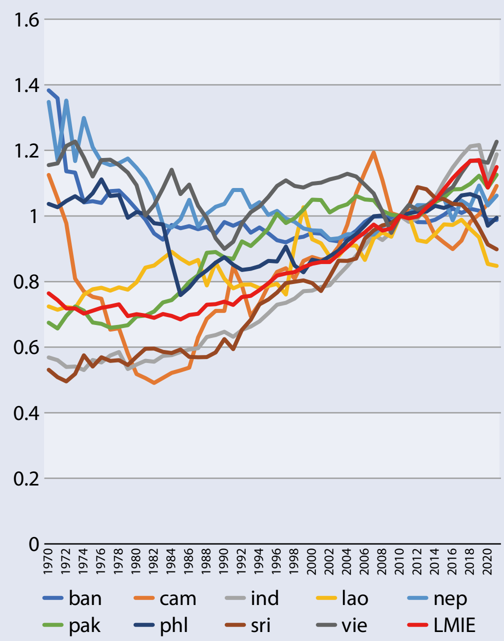
TREND OF LABOR PRODUCTIVITY IN LOWER MIDDLE INCOME APO ECONOMIES, 1970–2021



Source: Author's calculations based on the APO Productivity Database

FIGURE 1-5

TREND OF TOTAL FACTOR PRODUCTIVITY IN LOWER MIDDLE INCOME APO ECONOMIES, 1970–2021



Source: Author's calculations based on the APO Productivity Database

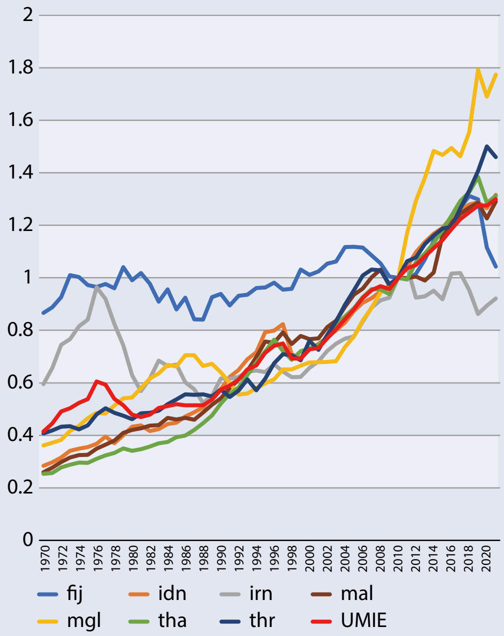
Figure 1-4 and 1-5 show the trends in labor productivity and TFP among lower-middle-income economies (LMIEs) in the APO from 1970 to 2021. Overall, most LMIEs demonstrated an upward trend in both labor productivity (LP) and TFP. Specifically, over the span of approximately 50 years, the average LP in LMIEs increased from 0.35 to 1.6, while TFP rose from 0.76 to 1.2. These may be driven by technological advancements, digitalization, or a shift of labor from low-productivity sectors such as agriculture to higher-productivity sectors like manufacturing and services.

Bangladesh and Sri Lanka in particular show an exceptional upward trend in terms of labor productivity, but a lagging TFP trend after the reference year compared to the weighted APO average. This discrepancy may indicate over-investment in capital or labor inefficiency within certain industries. For example, the economic structures of Bangladesh and Sri Lanka are particularly vulnerable to external shocks, with industries susceptible to international tensions, like tourism and agriculture, forming a significant part of their economies. Also, both countries have a high dependency on export, considering the fact that Bangladesh is the second-largest garment exporter, and Sri Lanka is the fourth-largest tea producer worldwide. Although they excel in volume, the value added per garment or unit of tea is relatively low compared to countries that focus on high-end or branded products.

Considering these factors, the high labor productivity in Bangladesh and Sri Lanka may be attributed to their abundant labor force. However, they face challenges related to low TFP. This contrasting trend signals the need for human capital development through education and skill training, aligned with technological advancement and incubation of domestic companies that can compete with the international market.

FIGURE 1-6

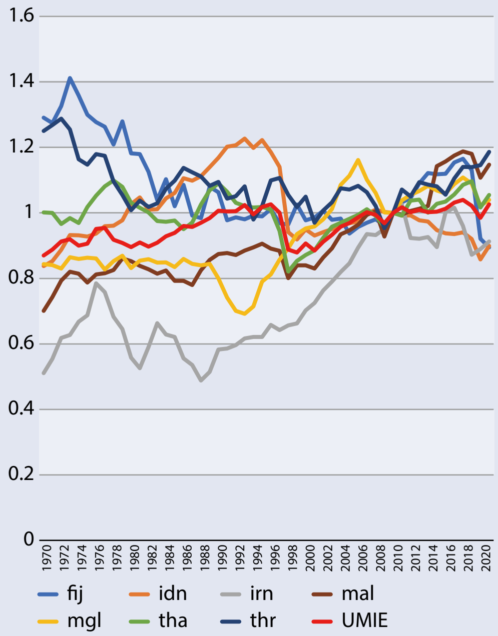
TREND OF LABOR PRODUCTIVITY IN UPPER MIDDLE INCOME APO ECONOMIES, 1970–2021



Source: Author's calculations based on the APO Productivity Database

FIGURE 1-7

TREND OF TOTAL FACTOR PRODUCTIVITY IN UPPER MIDDLE INCOME APO ECONOMIES, 1970–2021



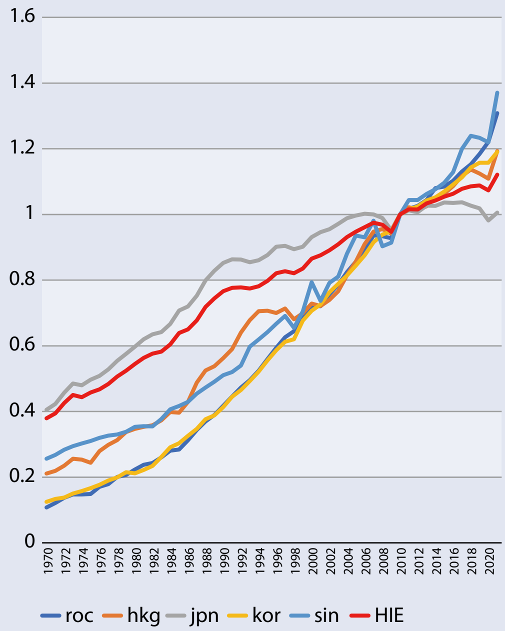
Source: Author's calculations based on the APO Productivity Database

Figures 1-6 and 1-7 illustrate the trends in overall labor productivity and TFP in Upper-Middle-Income APO economies (UMIEs) from 1970 to 2021. Most economies follow the trend of labor productivity in the weighted average of APO UMIEs, with exceptions in Mongolia and the Islamic Republic of Iran (I.R. Iran). Mongolia's exceptional labor productivity growth after 2000 can be attributed to a substantial increase in wage employment, which rose by 50 percent between 2000 and 2019 (World Bank, 2022). Despite this growth in labor productivity, Mongolia shows a notable downward trend in TFP during the same period, indicating inefficiencies in labor usage.

The challenges most UMIE countries face in the efficient utilization and management of human and capital resources are reflected in their TFP performance, as indicated by the lack of significant growth in TFP. Conversely, countries like Malaysia and Thailand exhibit stable trends in both labor productivity and TFP, remaining above the APO average after the reference year. One potential opportunity for the UMIEs to achieve productivity growth is through the expansion of global value chains (APO Productivity Outlook 2024, 2023). Economic diversification and further international trade integration can trigger a structural shift within these nations, enhancing spillover effects and boosting overall productivity.

FIGURE 1-8

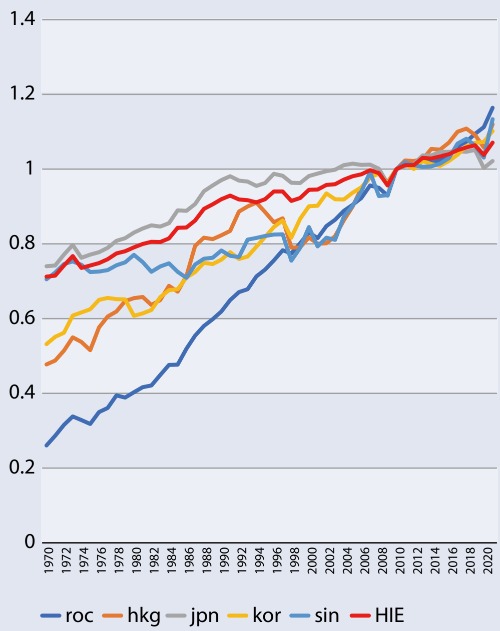
TREND OF LABOR PRODUCTIVITY IN HIGH INCOME APO ECONOMIES, 1990–2021



Source: Author's calculations based on the APO Productivity Database

FIGURE 1-9

TREND OF TOTAL FACTOR PRODUCTIVITY IN HIGH INCOME APO ECONOMIES, 1990–2021



Source: Author's calculations based on the APO Productivity Database

Figures 1-8 and 1-9 illustrate the trends in labor productivity and TFP of high-income economies (HIEs), both of which exhibit a smooth upward trajectory. Japan, in particular, exhibited exceptional performance in both labor productivity and TFP up until the reference year.

The lagging trend in productivity growth can be explained from various perspectives. Demographically, high-income economies initially benefited from a rising share of the working-age population but now face a huge social cost supporting an aging population (Bank of Japan, 2016). Socioeconomically, these economies have already achieved significant advancements in education, healthcare, technology, and governance. While further progress in these areas may contribute to additional labor productivity and TFP growth, it is unlikely to reach the levels previously achieved.

2.2 Sectoral Productivity

The increase in labor productivity within a country is driven by two main factors. First, productivity can be enhanced through capital accumulation within industries, technological innovation, and efficient resource allocation across companies. Second, overall productivity can improve as labor shifts from low-productivity sectors to high-productivity sectors.

We decompose the aggregate changes in labor productivity into two components using the framework developed by McMillan and Rodrik (2016):

$$\Delta P_t = \underbrace{\sum_{i=1}^{n} \theta_{i,t-k}\, \Delta p_{i,t}}_{\text{within-effect}} + \underbrace{\underbrace{\sum_{i=1}^{n} \Delta\theta_{i,t}\, p_{i,t-k}}_{\text{static effect}} + \underbrace{\sum_{i=1}^{n} \Delta\theta_{i,t}\, \Delta p_{i,t}}_{\text{dynamic effect}}}_{\text{between effect or structural change}} \qquad (1)$$

Equation (1) is rearranged as equation (2):

$$\Delta P_t = \sum_{i=1}^{n} \theta_{i,t-k}\, \Delta p_{i,t} + \sum_{i=1}^{n} \Delta\theta_{i,t}\, p_{i,t} \qquad (2)$$

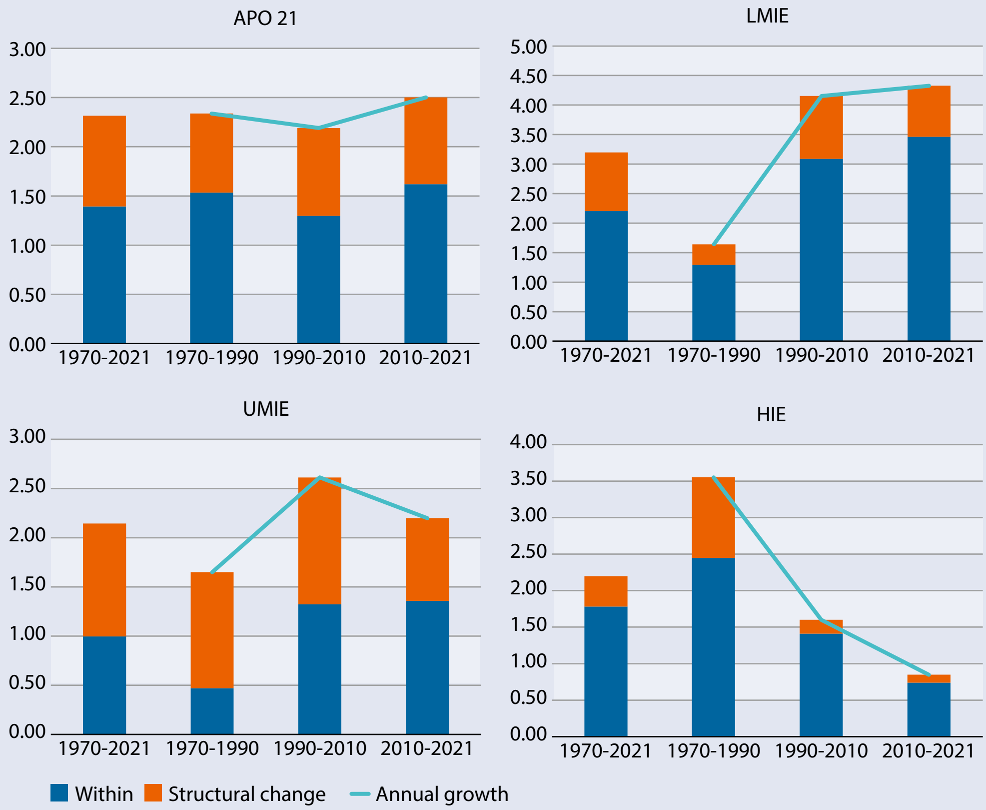
where ΔP_t refers to the change in aggregate labor productivity between period t-k and t. $\theta_{i,t}$ is the share of employment in sector i at time t.

In equation (2), the first term is the "within-sector" component, which measures changes in labor productivity within individual industries. This within-sector effect (hereafter referred to as the within effect) reflects the impact of factors such as technological advancements, efficiency improvements, and enhancements in work practices. The second term is the "structural change" component, which captures growth resulting from the reallocation of labor across sectors with different levels of productivity. Structural change indicates how shifts in employment shares between industries affect overall labor productivity, illustrating the effect of moving resources from low-productivity industries to high-productivity industries, thereby enhancing overall productivity.

This study analyzed all 21 APO member economies according to income groups, Lower-Middle-Income Economies (LMIE), Upper-Middle-Income Economies (UMIE), and High-Income Economies (HIE), across four time periods, 1970–90, 1990–2010, 2010–21, and 1970-2021. Figure 1-10 presents the result of decomposing the results of labor productivity into within effect and structural change (between effect), based on Equation (2) as percentage change rate for the overall industry.

FIGURE 1-10

DECOMPOSITION OF LABOR PRODUCTIVITY GROWTH IN 21 APO MEMBER ECONOMIES



Source: Author's calculations based on the APO Productivity Database

Two key characteristics can be observed from the decomposition analysis results. First, for all 21 APO member economies, the within effect was found to be larger than the structural change effect throughout the analysis period. When further divided into LMIE, UMIE, and HIE groups, the within effect remained greater than the structural change effect in all segments, except for labor productivity in UMIEs during the 1970–90 period. These results suggest that increases in labor productivity across all APO member economies were more significantly driven by technological advancements, improvements in efficiency, and other within-industry factors, rather than by the reallocation of labor between industries.

Second, when classified by income group, the composition and proportion of effects varied across the groups. Notably, labor productivity in the LMIEs increased dramatically, with a slight rise in the contribution of the between effect. In the case of UMIEs, labor productivity experienced a rapid increase between the first period (1970–90) and the second period (1990–2010), followed by a slight decline in the third period (2010–21). Among the three groups, UMIEs showed the largest contribution of structural change to labor productivity. Meanwhile, HIEs demonstrated a continuous decline in labor productivity throughout the entire analysis period.

Figure 1-11 decomposes the sectoral contributions to productivity growth, distinguishing between within-sector effects and structural change effects. First, examining the within-sector effect, it is evident that agriculture (AGR) and manufacturing (MAN) play key roles. In the 21 APO countries, manufacturing (MAN) contributed the most throughout the entire analysis period, while the contribution from agriculture (AGR) increased from the first period (1970–90) to the third period (2010–21). Notably, in LMIEs, the contribution from agriculture (AGR) is particularly significant. This can be attributed to factors such as the expansion of agricultural mechanization, improvements in crop varieties, development of agricultural infrastructure, and growth in agricultural exports. By contrast, UMIEs show a pronounced negative contribution from the mining (MIN) sector. This negative effect is likely due to adverse economic factors, such as the oil crises of the 1970s and the international debt crisis of the 1980s. For HIEs, manufacturing (MAN) shows a substantial positive contribution. This is likely driven by a transition from basic manufacturing to high-value-added industries, industrial innovations such as automation and digitalization, and integration into global value chains.

The analysis of the structural change effect revealed several common trends across all income groups. First, all income groups exhibited a negative contribution from the agricultural (AGR) sector throughout the entire analysis period. This can be interpreted as a result of the shifting of resources from agriculture to other sectors, leading to a contraction of the agricultural sector and a reduction in its contribution to productivity growth. Additionally, FRB (Financial intermediation, real estate, renting, and business activities) emerged as one of the key sectors in all income groups. As resources from agriculture moved toward the service sectors, including WRT (Wholesale, Retail, and Transport), it is likely that this shift contributed to productivity growth. A distinctive feature observed only in HIEs was the negative contribution from the MAN (Manufacturing) sector and the positive contribution from the CSP (Community, Social, and Personal Services) sector. In high-income economies, industrial upgrading shifted the center of growth from manufacturing to services, with the public service sector growing particularly rapidly, thereby having a positive impact on productivity growth.

As observed above, both agriculture and manufacturing play a crucial role in the economic growth of all APO member economies. Additionally, the services sector shows a positive contribution in both the within-sector and structural change effects, indicating that this sector is a key driver of economic growth in APO member economies. Therefore, in the following chapters, we will analyze agriculture, manufacturing, and services separately.

FIGURE 1-11

SECTOR CONTRIBUTION TO OVERALL WITHIN-SECTOR AND STRUCTURAL CHANGE PRODUCTIVITY GROWTH BY INCOME GROUP

Note: AGR (Agriculture, hunting, forestry, fishing), MIN (Mining and quarrying), MAN (Manufacturing), CON (Construction), CSP (Community, social and personal services), EGW (Electricity, gas and water supply), FRB (Financial intermediation, real estate, renting and business activities), TSC (Transport, storage and communications), WRT (Wholesale and retail trade, repair of vehicles and household goods, hotels and restaurants).
Source: Author's calculations based on the APO Productivity Database

3. Relationship Between Climate Change and Productivity

3.1. Literature Review

Since the Industrial Revolution, the global mean surface temperature has increased by approximately 0.85°C, with projections indicating a further rise of 0.9°C to 5.4°C by the end of this century (IPCC, 2018). Climate change is not only affecting temperatures, but also increasing the frequency and intensity of climate-related weather events such as heavy rainfall, droughts, and typhoons, which in turn have significant economic implications.

Recent studies have increasingly highlighted that these climate changes impact national productivity and economic growth, contingent upon industrial structures and adaptive capacities, and generate substantial social costs through the occurrence of extreme weather events. Productivity is one of the main channels through which climate change affects economies. Given that productivity is crucial for long-term economic growth, it is important to understand the mechanism of climate change on productivity, which suggests that the relationship between climate change and productivity is complex. Identifying the potential channels through which climate change affects productivity will help policymakers in APO economies respond to the adverse consequences of climate change.

Gert Bijnens et al. (2024) distinguish the channels affecting labor productivity by type of climate-related risk. They categorize climate-related risks as chronic physical risk, acute physical risk, and transition risk. Chronic physical risks, such as loss of agricultural land and shifts in tourism due to rising temperatures and sea levels, lead to higher mortality, sickness, climate-induced migration, and reduced labor efficiency.[1] These factors, combined with less productive capital investments in adaptation, divert resources from innovation. Acute physical risks involve the destruction of capital stock from disasters, leading to temporary improvements through the replacement of old capital with newer technology but also greater uncertainty and reduced investment willingness. These risks also result in higher mortality, disaster-induced migration, loss of education and skills, and localized economic disruptions due to bankruptcies. Transition risks, stemming from regulatory changes and carbon taxes, create stranded assets, increase short-term energy costs, and cause skill mismatches, leading to structural unemployment. While environmental regulations are expected to reduce productivity, they can also drive innovation, potentially offsetting some negative impacts (Table 1-1).

1 Chronic physical risk refers to the gradual and persistent effects of global warming, characterized by long-term shifts in climatic patterns.

TABLE 1-1

CHANNELS OF IMPACT OF CLIMATE-RELATED RISKS ON LABOR PRODUCTIVITY

Risk Type	Capital Stock	Labor Supply	TFP and Innovation
Chronic physical risk	- Loss of agricultural land to temperature, salinification of soil due to rising sea levels, and water stress - Shifts in tourism flows - Disruption of economic activity in coastal areas as sea levels rise	- Higher rates of mortality and sickness - Climate-induced migration - Reduced labor efficiency due to higher temperatures, including fewer hours worked	- Capital invested in adaptation less productive in aggregate and diverts resources away from innovation - Agglomeration effects from migration might be positive for productivity
Acute physical risk	- Destruction of capital stock due to disasters - Opportunity to replace old, destroyed capital with newer, more technologically advanced capital - Greater uncertainty and volatility reduce willingness to invest over the long run	- Higher rates of mortality and sickness - Disaster-induced migration - Loss of education and skills	- Disaster-caused bankruptcies and localized reductions in access to finance causes reallocation between firms, for better or worse - Rebuilding process distracts management, reducing overall productivity
Transition risk	- Increase in stranded assets - Higher energy costs from carbon taxes in the short term could reduce funds for investment	- Skill mismatches increasing structural unemployment - Economic migration	- Reallocation of output between firms within sectors may prove more or less efficient - Environmental regulations reduce productivity, perhaps offset by innovation

Source: Gert Bijnens et al. (2024).

Kumar and Maiti (2024) provide the theoretical framework to show the mechanisms by which rising temperatures, a consequence of climate change, have negative effects on TFP in emerging market economies (EMEs). The framework identifies three main channels through which temperature affects TFP: reduction in ecosystem services, decrease in labor productivity, and decrease in capital productivity.

$$\Delta \log TFP_t = -\frac{1}{1+\Phi}[\Phi logB + logD] - \frac{\Phi}{1+\Phi} logL - \frac{\alpha\Phi}{1+\Phi} logk_t \qquad (1)$$

where K and L indicate capital and labor, respectively. And $B = AA_K^{\alpha}A_L^{1-\alpha}$, $D = N^{-\Phi\sigma/(\sigma-1)}$, $\Phi = [\mu_A + \alpha\mu_K + (1-\alpha)\mu_L]\varphi$.[2] Φ represents the emission elasticity of global production.

2 A_K and A_L indicate capital and labor efficiency, respectively.

As shown in equation (1), productivity losses due to climate change come from three sources.[3] On the right-hand side, the first term represents the productivity loss associated with ecological damage. The second and third terms capture the loss of productivity due to damage to labor and capital efficiency, respectively. Hence, equation (1) implies that the temperature rise affects the efficiency losses of ecology, labor and capital, and these effects lead to a decrease in productivity.

Kumar and Maiti (2024) estimated the extent of damages by employing the cross-sectional augmented autoregressive Distributed Lag (CS-ARDL) model. They used the CS-ARDL technique to control for cross-sectional dependence, stochastic temperature trends, and heterogeneity for variations in the different climatic zones and industrial structures across countries. They find that TFP is negatively affected by temperature increase in the long run. Specifically, a one-degree increase in temperature is associated with a 3.22 percent reduction in TFP.

Meanwhile, Dell et al. (2012) show the mechanism through which weather shocks affect per-capita output, separately into "level effects" and "growth effects." The level effects and growth effects are represented by β and γ in equation (2);

$$g_{it} = g_i + \beta(T_{it} - T_{it-1}) + \gamma T_{it} \qquad (2)$$

where g_{it} refers to the growth rate of country i's per-capita output at time t and T indicates weather (e.g., temperature or precipitation etc.). Equation (2) is easily derived from the production function (eq. 3) and the productivity growth (eq. 4).

$$Y_{it} = A_{it} L_{it} e^{\beta T_{it}} \qquad (3)$$

$$\Delta A_{it} / A_{it} = g_i + \gamma T_{it} \qquad (4)$$

where Y_{it} is the aggregate output for country i at time t, A_{it} and L_{it} are productivity and labor input, respectively.

The level effects come from β in equation 3, which are short-term impacts that affect the level of output or productivity at time t (current time). The growth effects appear through γ in equation 4, which are long-term impacts that persistently affect the growth rate of output or productivity over time. Thus, Dell et al. (2012) argue that the impact of climate change on productivity is the result of a combination of level and growth effects.

Using the empirical specification from equation (2), Dell et.al. (2012) found that a 1°C increase in temperature reduces the economic growth rate of poor countries by 1.3 percentage points annually, with both immediate and persistent negative effects on economic performance. However, the effects of changes in precipitation are ambiguous and less statistically significant.

In conjunction with theoretical approaches, as climate change emerges as a critical global issue, there is a growing body of empirical research exploring the relationship between extreme weather and economic output and productivity. In the existing literature, proxy variables for extreme weather include temperature, storms, heat, drought and heavy precipitation, etc.

3 All of the terms on the right side are negative, indicating the loss of each component.

The existing empirical literature highlights significant impacts of temperature, storms, and heat on economic output, labor allocation, productivity (labor productivity and TFP). Higher temperatures are negatively correlated with economic output (Hsiang et al., 2013; Burke et al., 2015; Casey et al., 2022; Tol, 2022; Chang et al., 2023). Niemela et al. (2022), Adhvaryu et al. (2020), and Gosling et al. (2018) show that elevated temperatures reduce labor productivity, but adaptations such as cooling systems and LED lighting can mitigate these effects. Zivin and Hsiang (2015) illustrate the adverse effects of extreme heat on labor productivity, particularly in outdoor and physically demanding sectors, underscoring the importance of climate control technologies and adaptation strategies. Zivin et al. (2014) underscores how high temperatures alter labor and leisure time allocation, necessitating adaptive measures in climate-exposed industries. Acevedo (2016) and Anttila-Hughes et al. (2013) highlight the economic damages from tropical cyclones and typhoons, emphasizing the need for robust disaster response policies.

These studies suggest that extreme weather, which is intensified by climate change, significantly impacts economic output and productivity. However, while most existing studies empirically analyzed the relationship between climate change and economic output, there is still a lack of research on the impact of climate change on productivity.

3.2. Relationship between Climate Change and Overall Productivity

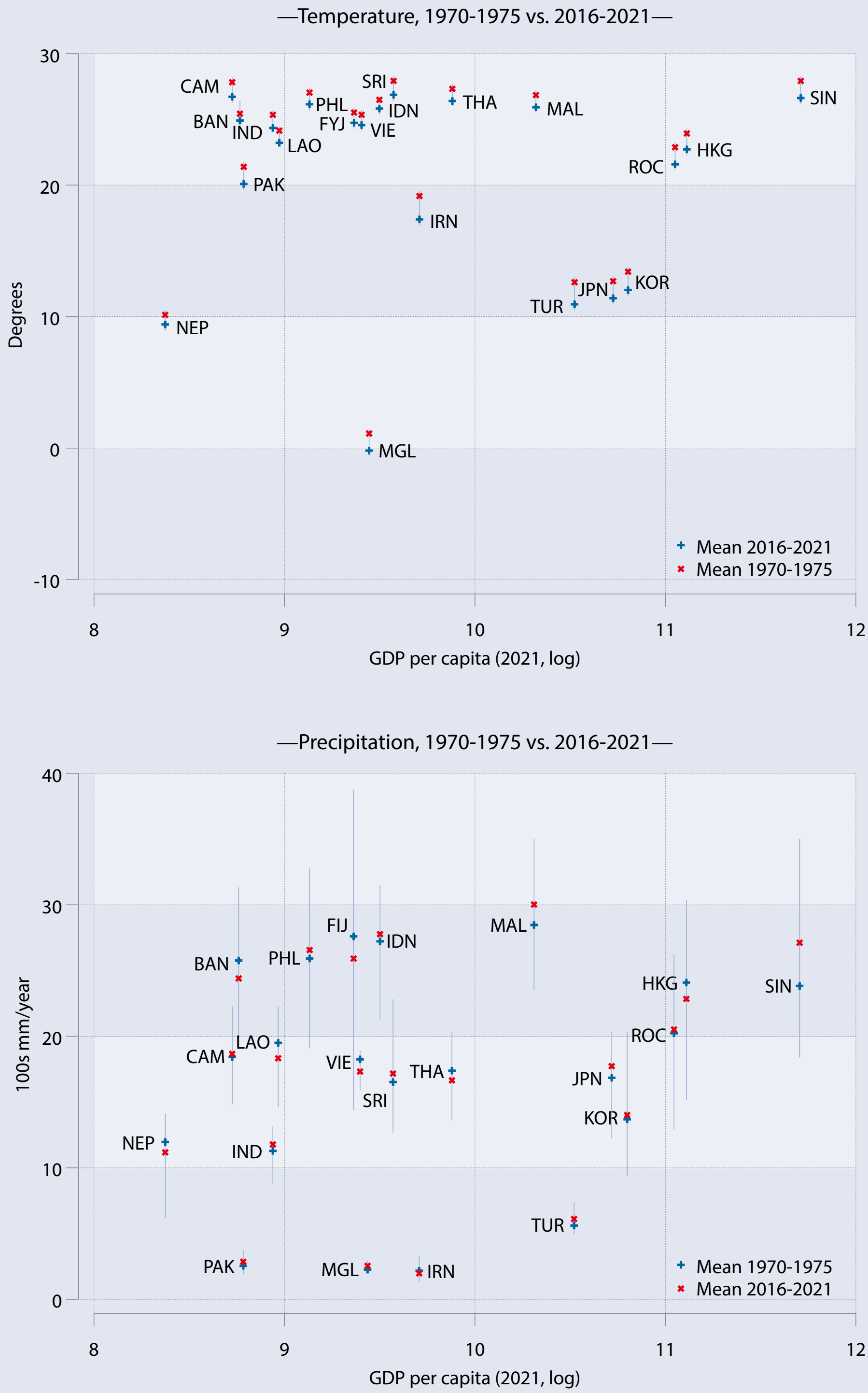
The average level of temperature in APO member economies has been increasing since 1970. Figure 1 illustrates the changes in the average temperature across APO member economies, comparing two periods: 1970–75 and 2016–21. Figure 1-12 shows an increase in temperatures across all APO member economies, which became 1.13°C warmer between the two periods.

For precipitation, there were different trends among APO member economies. As shown in Figure 1-13, Singapore, Malaysia, the Philippines, and Japan recorded increases in precipitation, while Fiji, Bangladesh, Lao PDR, Hong Kong, and Nepal showed decreases between the two periods.[4]

4 Precipitation has shown different trends across APO members, making it difficult to determine how these changes have affected their economies.

FIGURE 1-12

CHANGES IN TEMPERATURE AND PRECIPITATION IN APO MEMBER ECONOMIES

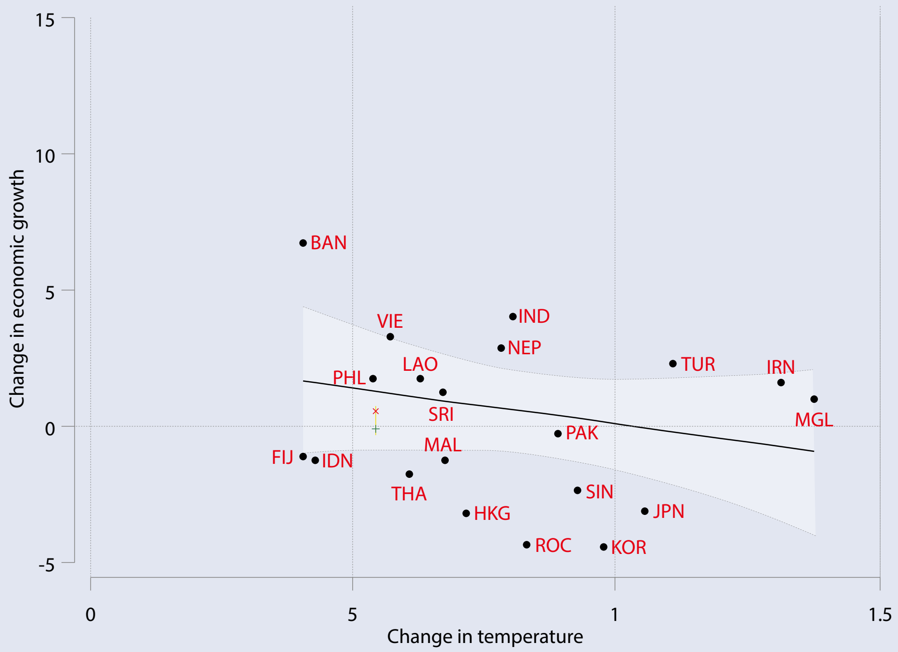


Source: Author's calculations based on the World Meteorological Organization (WMO) and APO Database

Figure 1-13 suggests that climate change is expected to affect their economies through some channels. To figure this out, we plot the relationship between temperature and economic growth. Figure 1-13 shows a downward sloping relationship between two variables. However, it is not statistically significant.[5]

FIGURE 1-13

RELATIONSHIP BETWEEN ECONOMIC GROWTH AND TEMPERATURE



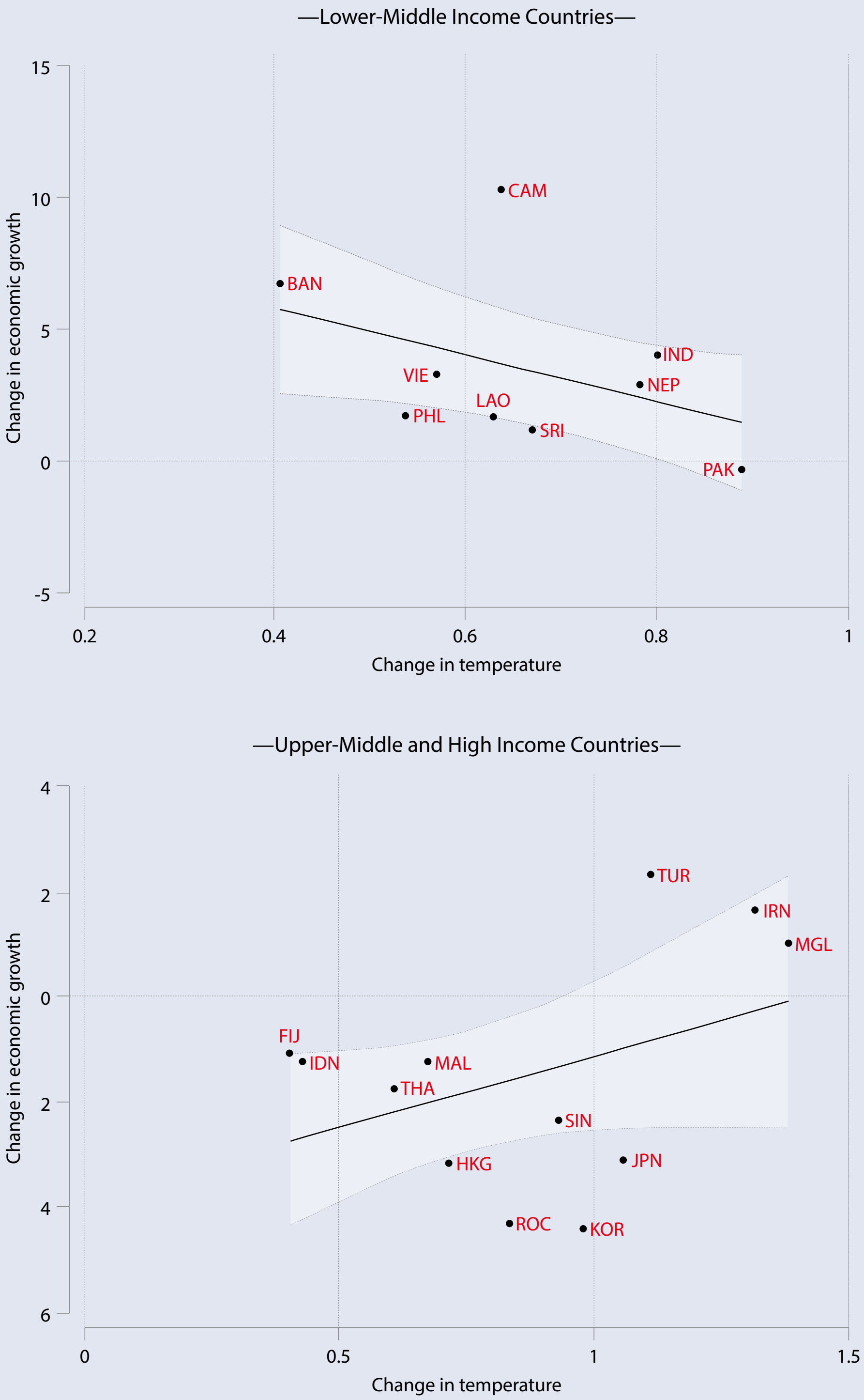
Source: Author's calculations based on the World Meteorological Organization (WMO) and APO Database

To examine whether the relationship differs by income level, we divided the APO members into two groups: lower-middle income countries and upper-middle and high-income countries. As illustrated in Figure 1-14, lower-middle income countries show a downward-sloping relationship between temperature and economic growth that is statistically significant,[6] while upper-middle and high-income countries display an upward-sloping relationship that is not statistically significant.[7]

5 The estimated coefficients are -2.67 (s.e.=2.54).
6 The estimated coefficients are -8.92 (s.e.=4.24).
7 The estimated coefficients are 2.69 (s.e.=1.71).

FIGURE 1-14

ECONOMIC GROWTH AND TEMPERATURE: HETEROGENEOUS RELATIONSHIP



Source: Author's calculations based on the World Meteorological Organization (WMO) and APO Database

Although Figure 1-13 and Figure 1-14 explored a simple relationship between two variables without controlling for other variables, these results suggest that climate change is likely to affect their economies. Against this backdrop, we analyze the effects of climate change on overall productivity of APO member economies. Based on equation (2), we set up the following empirical equation.

$$\Delta \log A_{it} = \gamma_r + \pi_{rt} + \tau_{pt} + \beta_j T_{it-j} + \epsilon_{it} \quad (5)$$

where A_{it} refers to country i's labor productivity or TFP at time t and T indicates temperature. γ_r, π_{rt}, and τ_{pt} are region fixed effect, region and time interaction fixed effects, and lower income and time interaction fixed effects, respectively.

Table 1-2 reports the results of the effects of temperature on TFP and labor productivity. In columns (1) and (2) of Table 1-2, TFP is used as the dependent variable, while in Columns (3), (4) and (5), labor productivity is used. As shown in columns (1) and (2), temperature has a statistically significant negative relationship with TFP on average across APO member economies. In column (2), we include an interaction term between temperature and low-income countries,[8] given that Figure 1-14 shows only lower-middle income countries among APO members have a statistically significant negative relationship between temperature and economic growth. The coefficient on the interaction term is also negative, but it is not statistically significant. This result suggests no clear evidence that the impact of temperature on TFP differs significantly between low-income and high-income countries, implying that temperature affects all APO member economies regardless of income level.

As a robustness test, we analyze the effects of temperature on labor productivity in columns (3), (4), and (5). In column (3), the coefficient is negative but not statistically significant. However, after controlling for additional factors, the coefficient on temperature becomes -0.083 and is highly significant at the 1% level. Similarly, as with the results in column (2), the interaction term remains insignificant. Column (5) represents the results when the precipitation variable is included in the model. The temperature variable remains highly significant, showing a consistent negative impact on labor productivity. In terms of precipitation, the coefficient is statistically significant and negative (-0.001), but it has small impact on labor productivity. As previously noted, Malaysia, the Philippines and Japan recorded increases in precipitation, while Fiji, Bangladesh, Lao PDR, Hong Kong, and Nepal showed decreases (Figure 1-12). The interaction term between precipitation and low income is also negative and statically significant, suggesting that the negative impact of precipitation on labor productivity is more pronounced in low-income countries. However, the coefficient (-0.002) is very small.

These results suggest that a 1-degree increase in temperature is estimated to reduce labor productivity by 2.8% to 8.3%, depending on the estimation model. Between 1970 and 2021, temperatures in APO members rose by 1.13 degrees, leading to a cumulative decline in labor productivity of approximately 3.2% to 9.4%.

8 In the empirical analysis, we defined low-income countries among the APO members as those with a GDP per capita (PPP) below the median in the first year of the analysis period (1970–2021).

TABLE 1-2

EMPIRICAL RESULTS: EFFECTS OF TEMPERATURE ON PRODUCTIVITY

	TFP		Labor productivity		
	(1)	(2)	(3)	(4)	(5)
T	-0.048** (0.019)	-0.021** (0.004)	-0.046 (0.052)	-0.083*** (0.007)	-0.028*** (0.001)
T*Low-income		-0.079 (0.110)		0.112 (0.184)	0.186 (0.185)
P					-0.001*** (0.185)
P*Low-income					-0.002*** (0.000)
Region*Year FE	No	Yes	No	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
R2	0.49	0.49	0.43	0.48	0.48
Observations	918	918	918	918	918

Notes: 1) Robust standard errors of the estimated coefficients are reported in parentheses.
2) Intercept is included, not reported.
3) ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.
Source: Author's calculation

<Table 1-3> and <Table 1-4> show the cumulative impacts of temperature on TFP and labor productivity, respectively. The coefficients on temperature remain negative and stable point estimates, but the impact of temperature on TFP is relatively small compared to its impact on labor productivity. With 3 lags included, a one-time 1°C increase in temperature reduces TFP growth by 0.022 percentage points and labor productivity growth by 0.066 percentage points, respectively. However, while the cumulative effects with 10 lags on labor productivity are no longer statistically significant,[9] the effect on TFP remains statistically significant at the 10% level. These results suggest that the effects of temperature on TFP persist longer than on labor productivity, but the magnitude of the effects is larger for labor productivity.

TABLE 1-3

EMPIRICAL RESULTS: CUMULATIVE IMPACT OF TEMPERATURE ON TFP

	No lags	3 lags	5 lags	7 lags	10 lags
Cumulative effects	-0.021**	-0.022**	-0.020**	-0.021**	-0.019*
F-Test	-	46.1 [0.021]	41.9 [0.023]	45.8 [0.021]	17.9 [0.052]

Notes: 1) p-values are reported in square brackets.
2) ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.
Source: Author's calculation

9 I conduct a joint significance test to assess whether the cumulative effects of temperature have a significant impact on TFP and labor productivity. The F-statistic is reported in <Table 1-?> and <Table 1-?>.

TABLE 1-4

EMPIRICAL RESULTS: CUMULATIVE IMPACT OF TEMPERATURE ON LABOR PRODUCTIVITY

	No lags	3 lags	5 lags	7 lags	10 lags
Cumulative effects	-0.083***	-0.066***	-0.044**	-0.051**	-0.030
F-Test	-	118.4 [0.008]	37.2 [0.025]	27.8 [0.034]	7.2 [0.116]

Notes: 1) p-values are reported in square brackets.
2) ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.
Source: Author's calculation

4. Conclusion

Our findings indicate that climate change, particularly through rising temperatures and fluctuating precipitation patterns, have statistically significant effects on productivity across APO member economies. The negative impact of climate-related risks on both labor productivity and TFP underscores the need to develop robust evidence-based policies. These challenges, stemming from both chronic physical risks (e.g., gradual temperature increases) and acute physical risks (e.g., extreme weather events), highlight the need for tailored strategies to mitigate productivity losses and support economic resilience.

First, it is essential to implement evidence-based adaptation policies that address the specific adverse effects of climate change on productivity. As temperature rises, labor productivity, especially in temperature-sensitive industries, declines, making targeted adaptation policies a priority. By focusing on labor-intensive and climate-sensitive sectors, adaptation policies can be tailored to support workforce health and productivity under changing environmental conditions.

Second, investments in resilient infrastructure and advanced technology are critical to strengthening the capacity of capital stock and labor supply to endure climate-related risks. Upgrading facilities to withstand higher temperatures and adopting advanced climate-adaptive technologies can help mitigate the immediate impacts on productivity. For instance, implementing enhanced cooling systems in indoor manufacturing environments and weather-resistant infrastructure in agriculture can reduce operational disruptions and foster continuity in productivity.

Third, promoting technological innovation and efficiency is essential to sustain TFP growth amid escalating climate challenges. Investments in research and development focused on energy-efficient and climate-resilient technologies can drive productivity improvements even under adverse conditions. Innovation can play a transformative role by creating solutions that reduce energy consumption, improve resource use, and lower dependency on fossil fuels, ultimately enhancing productivity resilience.

Fourth, strengthening regional cooperation among APO member economies is crucial for shared learning and mutual support. Climate change is a transnational challenge, and APO economies can benefit greatly from the exchange of best practices, resource-sharing, and collaborative research. By pooling knowledge and resources, member economies can accelerate the adoption of effective climate adaptation and mitigation strategies, bolstering collective resilience against climate impacts.

Finally, industry-specific analysis is essential due to the heterogeneity in climate change impacts across sectors. Climate change affects industries differently, with agriculture, manufacturing, and services each facing unique productivity challenges. Understanding the distinct effects on each sector enables policymakers to tailor interventions that address sector-specific vulnerabilities.

In light of these findings, Chapters 2, 3, and 4 will examine the impact of climate change on productivity in agriculture, manufacturing, and services, respectively, and derive evidence-based adaptation and mitigation strategies tailored to each sector's unique challenges.

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CLIMATE CHANGE ON AGRICULTURAL PRODUCTIVITY AND POLICY IMPLICATIONS

1. Introduction

The agricultural sector in Asia is at a critical crossroads as it grapples with the urgent and escalating challenge of climate change. The region's agriculture is profoundly affected by climate variability and extreme weather events, which threaten food security, economic stability, and the livelihoods of millions. Climate change is not only altering weather patterns, but is also increasing the frequency and intensity of extreme events such as droughts, floods, and storms, thereby exacerbating the vulnerabilities of the agricultural sector (Smith & Olesen, 2010; Wang et al., 2015). Understanding and addressing these impacts is imperative for ensuring the sustainability and resilience of agriculture in Asia.

One of the most significant impacts of climate change on agriculture in Asia is the increase in average temperatures. For instance, in India, rising temperatures have been linked to reduced yields in staple crops such as wheat and rice. A study by the Indian Council of Agricultural Research (ICAR) found that wheat yields could decrease by 6–23% by 2050 due to heat stress. Similar trends are observed in China, where increased temperatures have negatively affected rice productivity in the Yangtze River Basin. These temperature increases not only reduce crop yields but also exacerbate water scarcity, as higher temperatures increase evaporation rates and water demand for irrigation.

Changes in precipitation patterns are another critical factor affecting agricultural productivity in Asia. In Southeast Asia, unpredictable rainfall patterns have disrupted planting and harvesting schedules. For example, Vietnam, one of the world's largest rice exporters, has experienced significant variability in monsoon rains, leading to either drought conditions or flooding. This variability poses a severe threat to rice production, which is highly dependent on stable water supply. In Bangladesh, erratic rainfall patterns have affected both the quantity and quality of agricultural produce, impacting food security and the livelihoods of millions of smallholder farmers.

Extreme weather events, such as typhoons and cyclones, also pose significant threats to agriculture in Asia. The Philippines, frequently hit by typhoons, suffers substantial agricultural losses each year. Typhoon Haiyan in 2013, one of the strongest tropical cyclones ever recorded, devastated large swathes of agricultural land, resulting in losses amounting to over USD700 million. Similarly, in 2020, Cyclone Amphan caused extensive damage to agriculture in India and Bangladesh, affecting millions of hectares of crops and leading to severe economic losses. These events highlight the urgent need for robust disaster management and resilient agricultural practices.

To address these challenges, it is crucial to implement effective adaptation and mitigation strategies. One example of a successful adaptation strategy is the introduction of climate-resilient crop varieties. In India, the development and adoption of drought-resistant rice and wheat varieties have helped mitigate the impacts of water scarcity and heat stress. In the Philippines, salt-tolerant rice varieties have been introduced to cope with saline water intrusion caused by rising sea levels. Additionally, improving irrigation efficiency through technologies such as drip irrigation and rainwater harvesting can help optimize water use and reduce vulnerability to changing precipitation patterns.

Policy interventions and regional cooperation are also essential for building resilience in the agricultural sector. Governments in Asia are increasingly recognizing the need for climate-smart agriculture policies. For instance, China's National Plan on Climate Change includes measures to enhance the resilience of agricultural infrastructure, promote sustainable farming practices, and improve the monitoring and management of climate risks. Regional cooperation initiatives, such as the ASEAN Climate Resilience Network, aim to facilitate the sharing of knowledge and best practices among member states, promoting collaborative efforts to tackle climate challenges.

The purpose of this study is to provide a comprehensive analysis of the direct impacts of climate change on agricultural productivity in Asia and to explore effective adaptation and mitigation strategies to address these challenges. By leveraging data from the APO and employing rigorous analytical methods, this research aims to offer valuable insights and actionable recommendations. Understanding the multifaceted impacts of climate change on agriculture will help policymakers and stakeholders develop targeted responses to safeguard food security, economic stability, and the livelihoods of millions across the region. This study's findings will contribute to informed decision-making and strategic planning, promoting resilience and sustainability in Asia's agricultural sector amid the growing threats posed by climate change. Through this structured approach, we hope to support the region's efforts in building a more climate-resilient agricultural future.

2. Literature Review

Climate change significantly reduces agricultural productivity, with extreme weather events exacerbating this negative impact. Wing et al. (2021) employed a fixed-effects panel model to highlight the global reduction in crop yields without adaptive measures, with severe losses in countries reliant on agricultural exports. Similarly, Liang et al. (2017) and Rahman et al. (2022) examined the impact of climate factors on U.S. and global agricultural productivity, respectively, both concluding that temperature and precipitation fluctuations contribute to declines in TFP. The detrimental effects of climate change were further underscored by Sarker et al. (2014), who used the Just-Pope production function to project increased rice yield variability in Bangladesh, stressing the importance of national-level adaptation efforts.

Various studies have emphasized the importance of regionally differentiated climate change adaptation strategies to mitigate the adverse effects on agriculture. Xiang et al. (2022) highlighted the uneven effects of climate change, noting that while developed countries might benefit, developing nations face greater challenges. This was corroborated by Mendelsohn (2009), who used the Ricardian method to demonstrate the country-specific impacts of climate change, recommending tailored adaptation policies. In a similar vein, Vogel et al. (2019) analyzed yield variability during extreme weather events, advocating for region-specific strategies to stabilize agricultural productivity.

Extreme weather events, such as droughts and high humidity, have been found to increase pest outbreaks and further reduce agricultural yields. Choi et al. (2020) applied a panel GLS model, demonstrating how climate-induced pest outbreaks negatively affect cabbage and radish yields.

Additionally, Silva et al. (2019) found that rising temperatures and reduced rainfall were detrimental to sugarcane productivity in Brazil, with irrigation identified as a critical adaptation strategy to mitigate these adverse effects in arid regions.

Numerous studies have explored the role of environmental degradation and climate factors on agricultural productivity in various regions. Salahuddin et al. (2020) focused on Sub-Saharan Africa, showing that environmental degradation, such as deforestation and land degradation, negatively affects agricultural productivity. Similarly, Amare et al. (2018) demonstrated that the lack of rainfall in Nigeria had disproportionately negative impacts on low-income farmers, underlining the need for income-sensitive adaptation strategies.

Adaptation strategies play a critical role in mitigating the negative impacts of climate change on agriculture. Howden et al. (2007) reviewed a variety of adaptation strategies, concluding that improving agricultural systems and implementing measures to cope with extreme weather events are essential. In a related study, Iglesia et al. (2011) developed an Adaptive Capacity Index to assess the differences in climate change adaptation capacity among Mediterranean countries. Similarly, Rahman et al. (2022) called for policy measures such as crop diversification, increased education, and investment in research and development (R&D) to address global agricultural productivity losses due to climate change.

Technological innovations and strategic interventions are essential in bolstering agricultural resilience to climate change. Imelda and Hidayat (2024) employed PRISMA analysis to evaluate the potential of Indonesia's climate adaptation strategies, finding that technology adoption and the development of climate-resistant crops could enhance farmer welfare. Mogess and Ayen (2023) demonstrated, through multinomial panel endogenous switching regression, that practices such as crop rotation and seed development improved household welfare in regions adapting to climate change.

Adaptation strategies such as irrigation, biochar, and plastic mulching have been shown to reduce the negative impacts of extreme weather on agricultural yields. Lychuck et al. (2017) used the EPIC model to examine U.S. crop yields, finding that biochar and irrigation were effective, though their benefits varied by crop and region. Similarly, Dong et al. (2017) analyzed ridge-furrow cultivation and plastic mulching in China, showing how these techniques improved maize growth despite extreme weather conditions.

Long-term climate adaptation strategies are essential for mitigating the ongoing effects of rising temperatures and climate variability. Mérel and Gammans (2021) found that short-term negative effects of rising temperatures could be alleviated through long-term adaptation, such as altering planting schedules and improving irrigation practices. Tan et al. (2021) emphasized farm-level adaptation strategies in Malaysia to cope with climate change, particularly in rice production, where temperature and rainfall fluctuations were shown to severely affect yields.

TABLE 2-1

PREVIOUS RESEARCH ON THE IMPACT OF CLIMATE CHANGE ON AGRICULTURAL PRODUCTIVITY

Authors	Climate change policy	Effect on agricultural productivity
Wing et al. (2021)	Adaptation	Global crop yield reductions, severe losses in export-reliant countries.
Liang et al. (2017), Rahman et al. (2022)	Adaptation	Declines in TFP due to climate variability.
Sarker et al. (2014)	Adaptation	Increased rice yield variability in Bangladesh.
Xiang et al. (2022)	Adaptation	Developing countries face greater challenges, uneven effects.
Mendelsohn (2009)	Adaptation	Country-specific impacts of climate change on productivity.
Vogel et al. (2019)	Region-specific strategies to stabilize agricultural productivity during extreme events.	Yield variability increases, necessitating region-specific strategies.
Choi et al. (2020)	Adaptation	Reductions in cabbage and radish yields due to pest outbreaks.
Silva et al. (2019)	Adaptation	Sugarcane productivity declines due to temperature and rainfall reduction.
Salahuddin et al. (2020)	Environmental degradation (deforestation) negatively impacts productivity.	Productivity declines due to environmental degradation.
Amare et al. (2018)	Adaptation	Low-income farmers disproportionately affected by rainfall shortage.
Howden et al. (2007)	Adaptation	Climate change negatively affects agriculture; adaptation required.
Iglesia et al. (2011)	Adaptation	Adaptation capacity varies by country, affecting productivity.
Rahman et al. (2022)	Adaptation	TFP losses due to climate change; adaptation essential.
Imelda and Hidayat (2024)	Adaptation	Enhanced farmer welfare due to technology and resilient crops.
Mogess and Ayen (2023)	Adaptation	Improved household welfare through adaptation practices.
Lychuck et al. (2017)	Adaptation	Yield improvements via biochar and irrigation.
Dong et al. (2017)	Adaptation	Maize growth improved despite extreme weather.
Mérel and Gammans (2021)	Adaptation	Short-term temperature effects alleviated by long-term adaptation.
Tan et al. (2021)	Adaptation	Rice yields severely affected by climate variability.

3. Background and Conceptual Review on Adaptation and Mitigation Strategies

Recent extreme weather events caused by climate change are occurring in various forms across the globe. The uncertainty associated with climate change is steadily increasing, and the resulting damage is expanding worldwide. To minimize this damage, the international community is developing climate change response strategies. Climate change response strategies are broadly divided into adaptation and mitigation.

Climate change adaptation refers to the process of anticipating the adverse effects of climate change and taking appropriate actions to prevent or minimize the damage these effects may cause (IPCC, 2022). Essentially, adaptation can be understood as the process of adjusting to the long-term effects of climate change. A representative example of climate change adaptation is the construction of defensive structures to prevent the risks associated with rising sea levels, thereby minimizing the potential damage from natural disasters. <Table 2-2> and <Figure 2-1> present data on the approved funding amount for multilateral climate change adaptation worldwide from 2003 to 2023. Since 2007, agriculture sector projects have been promoted and received funding approval. There has been a consistent increase in both the number of projects and the amount of funding approved for the agriculture sector.

TABLE 2-2

APPROVED FUNDING AMOUNT FOR AGRICULTURE SECTOR CLIMATE CHANGE ADAPTATION

(Unit: USD millions)

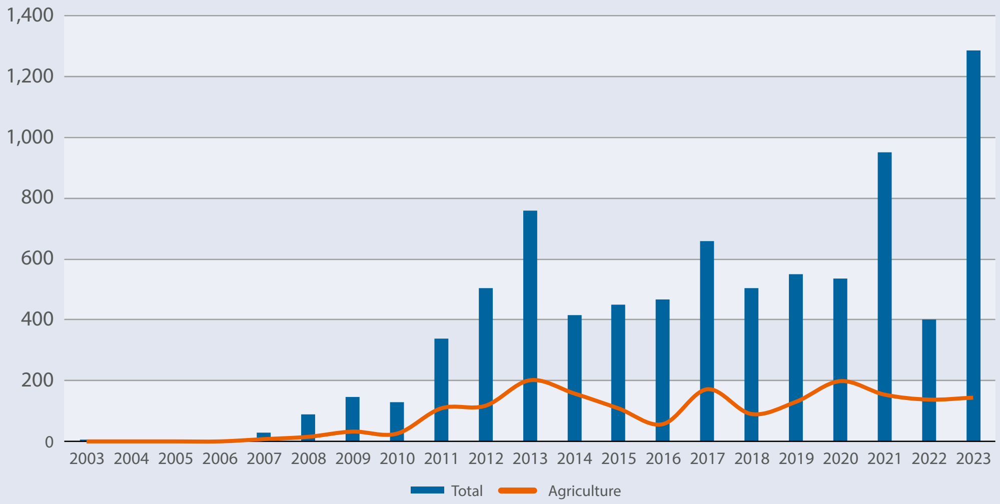
	Total Sector		Agriculture Sector		Agriculture Sector's Share of Total Sector	
Year	Number of Projects	Amount of Funding Approved	Number of Projects	Amount of Funding Approved	Number ratio	Amount of Funding Approved ratio
2003	18	4	-	-	-	-
2004	27	5	-	-	-	-
2005	1	-	-	-	-	-
2006	1	1	-	-	-	-
2007	8	28	2	7	25.00%	27.00%
2008	23	88	5	15	21.74%	17.07%
2009	39	146	11	32	28.21%	21.97%
2010	21	128	6	25	28.57%	19.82%
2011	49	338	12	108	24.49%	32.08%
2012	72	505	19	117	26.39%	23.14%
2013	92	760	30	200	32.61%	26.36%
2014	64	415	23	157	35.94%	37.87%
2015	58	449	21	108	36.21%	24.09%
2016	65	468	11	57	16.92%	12.10%
2017	76	659	18	171	23.68%	25.94%
2018	61	504	6	90	9.84%	17.82%
2019	75	549	14	130	18.67%	23.58%
2020	61	534	13	198	21.31%	36.97%
2021	85	952	12	153	14.12%	16.11%
2022	85	402	22	137	25.88%	34.14%
2023	64	1285	15	143	23.44%	11.16%

Source: CFU, https://climatefundsupdate.org/
Note: Only includes projects where the purpose of the fund is about climate change adaptation. Years with no data are indicated with '-'.

FIGURE 2-1

APPROVED FUNDING AMOUNT FOR AGRICULTURE SECTOR CLIMATE CHANGE ADAPTATION

(Unit: USD millions)



Source: CFU, https://climatefundsupdate.org/
Note: Only includes projects where the purpose of the fund is about climate change adaptation.

The primary cause of global warming is the emission of greenhouse gases (GHGs) due to industrialization. Climate change mitigation involves strategies to reduce the emission of greenhouse gases into the atmosphere, thereby lessening the impacts of climate change. For example, reducing GHG emissions from various industrial sectors, increasing the share of renewable energy, and enhancing carbon sinks through afforestation are all methods of mitigating climate change. <Table 2-3> and <Figure 2-2> present data on the approved funding amount for multilateral climate change mitigation worldwide from 2003 to 2023. Compared to climate change adaptation, the approved funding amount for the agriculture sector in mitigation efforts is relatively small.

TABLE 2-3

APPROVED FUNDING AMOUNT FOR AGRICULTURE SECTOR CLIMATE CHANGE MITIGATION

(Unit: USD millions)

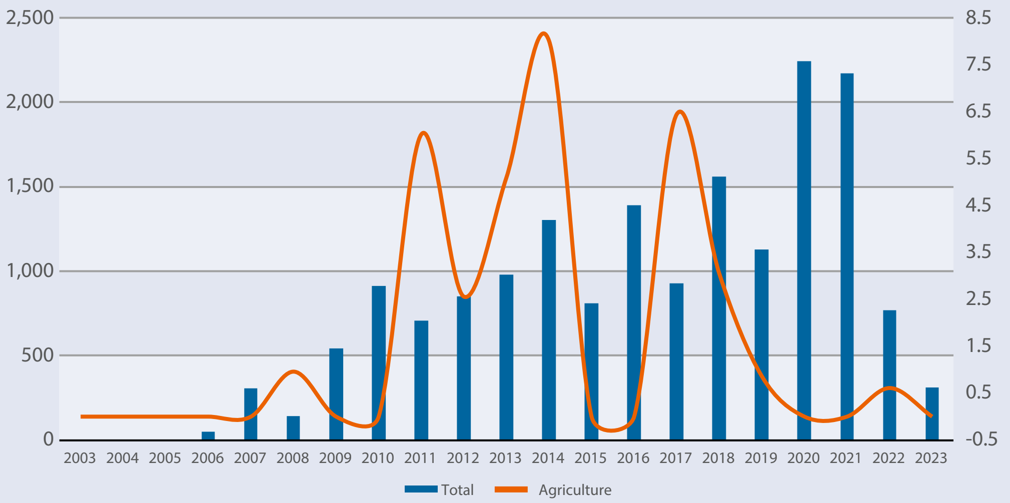
	Total Sector		Agriculture Sector		Agriculture Sector's Share of Total Sector	
Year	Number of Projects	Amount of Funding Approved	Number of Projects	Amount of Funding Approved	Number ratio	Amount of Funding Approved ratio
2003	-	-	-	-	-	-
2004	-	-	-	-	-	-
2005	-	-	-	-	-	-
2006	10	51	-	-	-	-
2007	36	306	-	-	-	-
2008	37	142	1	0.96	2.70%	0.68%
2009	80	544	-	-	-	-
2010	107	911	-	-	-	-
2011	61	705	1	6.02	1.64%	0.85%
2012	78	851	1	2.56	1.28%	0.30%
2013	106	977	1	5.10	0.94%	0.52%
2014	119	1,305	3	8.02	2.52%	0.61%
2015	94	809	-	-	-	-
2016	76	1,389	-	-	-	-
2017	82	930	2	6.45	2.44%	0.69%
2018	83	1,560	2	3.05	2.41%	0.20%
2019	47	1,128	1	0.86	2.13%	0.08%
2020	84	2,242	-	-	-	-
2021	72	2,174	-	-	-	-
2022	83	767	1	0.61	1.20%	0.08%
2023	36	313	-	-	-	-

Source: CFU, https://climatefundsupdate.org/
Note: Only includes projects where the purpose of the fund is about climate change mitigation. Years with no data are indicated with '-'.

FIGURE 2-2

APPROVED FUNDING AMOUNT FOR AGRICULTURE CLIMATE CHANGE MITIGATION

(Unit: USD millions)

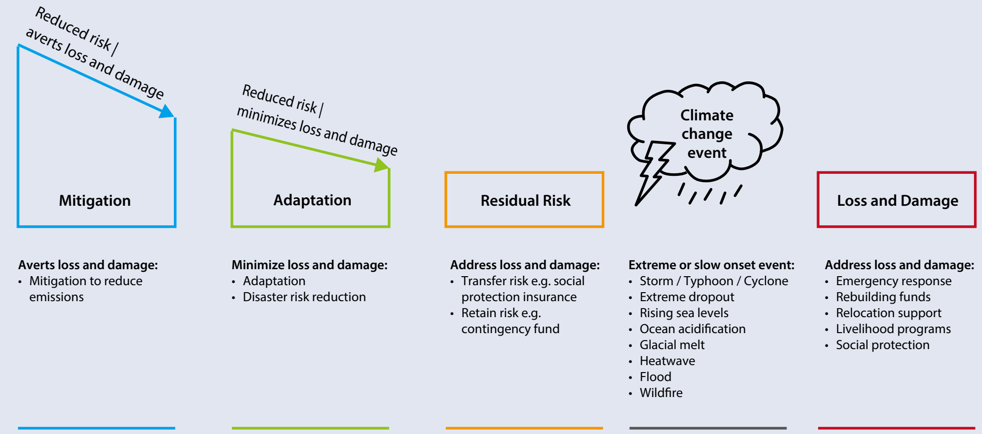


Source: CFU, https://climatefundsupdate.org/
Note: Only includes projects where the purpose of the fund is about climate change mitigation.

Climate change adaptation and mitigation are complementary strategies: mitigation reduces the risk of climate change occurring, while adaptation minimizes the damage caused by climate change. This relationship can be illustrated as shown in <Figure 2-3>, based on Richards (2022). Loss and damage refer to the impacts of climate change that occur because mitigation, adaptation, or disaster risk reduction (DRR) efforts were insufficient. Residual risk signifies the remaining climate change risks that persist despite the implementation of mitigation and adaptation measures.

FIGURE 2-3

AVERTING, MINIMIZING AND ADDRESSING LOSSES AND DAMAGES



Adapted from: Richards (2022).

Since 2015, APO members have been actively implementing climate change response projects focused on both adaptation and mitigation. A key area of emphasis across these countries is biodiversity conservation, as seen in the initiatives from I.R. Iran, Cambodia, Sri Lanka, and Malaysia. These countries have launched national strategies to protect biodiversity while addressing the impacts of climate change. For example, I.R. Iran's Revised National Biodiversity Strategies and Action Plan (NBSAP2) aims to ensure biodiversity conservation and sustainable development, while Sri Lanka's National Biodiversity Strategic Action Plan integrates climate resilience into its conservation efforts. Malaysia also focuses on biodiversity conservation in its National Policy on Biological Diversity 2016–25, addressing both adaptation and mitigation. In Cambodia, efforts extend to agricultural productivity through the development of sustainable agricultural technologies aimed at improving food security in a changing climate.

In addition to biodiversity, many countries are working to enhance climate resilience in other sectors. The Republic of Korea's (ROK) multiple legislative actions, such as the Act on the Sustainable Use of Timbers and the Act on the Management and Improvement of Carbon Sink, focus on promoting sustainable forestry practices, enhancing carbon sinks, and reducing greenhouse gas emissions. Fiji's Environmental Levy Act introduces environmental fees to support climate change response and environmental conservation activities, reflecting a financial approach to mitigation. Pakistan's National Food Security Policy, implemented in 2018, prioritizes food security by enhancing the agricultural sector's resilience to climate impacts. Collectively, these projects demonstrate a multifaceted approach to climate change, with a focus on biodiversity, sustainable agriculture, carbon sinks, and food security, tailored to the specific needs and challenges of each economy.

TABLE 2-4

CLIMATE CHANGE RESPONSE POLICIES BY GOVERNMENT

Economy	Project Name(year)	Climate change response	Relevant objective
Fiji	Environmental Levy (Budget Amendment) Act 2017 (2017)	Adaptation/ Mitigation	- Introduction of environmental fees - Support for environmental conservation and climate change response activities
I.R. Iran	Revised National Biodiversity Strategies and Action Plan (NBSAP2) 2016-2030 (2016)	Climate change	- Ensuring biodiversity conservation and sustainable development
Cambodia	Master Plan for Crop Production in Cambodia to 2030 (2016)	Climate change	- Improvement of agricultural productivity through agricultural technology development - Development of sustainable agricultural production technologies and ensuring food security
	National Biodiversity Strategy and Action Plan (2016)	Climate change	- Biodiversity conservation
ROK	Act on the Sustainable Use of Timbers (No. 11429 of 2016)	Climate change	- Response to climate change and enhancement of carbon sink functions
	Act on the Management and Improvement of Carbon Sink (2016)	Climate change	- Reduction of greenhouse gas emissions for realizing a low-carbon society
	Framework Act on Forestry (2015)	Climate change	- Conservation of forest resources and prevention of forest disasters
Sri Lanka	National Biodiversity Strategic Action Plan 2016-2022 (2016)	Climate change	- Biodiversity conservation
Malaysia	National Policy on Biological Diversity 2016-2025 (2016)	Adaptation/ Mitigation	- Biodiversity conservation
Pakistan	National Food Security Policy (2018)	Climate change	- Food security

4. Analyzing the Impacts of climate Change on Agricultural Productivity

Facing the urgent challenge of climate change, Asia's agricultural sector is at a critical juncture. The impacts of climate variability and extreme weather events pose significant threats to food security, economic stability, and the livelihoods of millions across the region (Smith & Olesen, 2010; Wang et al., 2015). To address these challenges comprehensively, it is imperative to employ a detailed and data-driven approach. This study proposes a leveraging of valuable productivity data from the APO to assess the direct impacts of climate change on agricultural productivity and to explore effective adaptation and mitigation strategies within the Asian context.

To facilitate a thorough analysis, this research will be divided into two approaches. The first approach will focus on the direct impacts of climate change on agricultural productivity in Asia, including the effects of temperature increases, changes in precipitation patterns, extreme weather events, and variations in CO_2 concentrations (Lobell et al., 2007). Utilizing fixed effects models, we aim to isolate and quantify the specific influences of these climate variables on agricultural output.

$$Y_{it} = \alpha_i + \beta_1 Temperature_{it}^2 + \beta_2 Precipitation_{it}^2 + \gamma X_{it} + \varepsilon_{it}$$

where Yit represents the agricultural productivity of country i in year t, Temperatureit, Precipitationit, are the climate change variables of interest, Xit includes control variables such as land use patterns and agricultural inputs (e.g., fertilizer use, irrigation), αi captures the fixed effects, which account for unobserved, time-invariant factors affecting each country or region, and ϵit is the error term.

The second approach will then shift focus towards identifying and evaluating effective adaptation and mitigation strategies that can help sustain and enhance agricultural productivity in the face of these climate challenges (Deressa et al., 2009 and Nhemachena & Hassan, 2007). The model can be represented as follows:

$$Y_{it} = \alpha_i + \sum_j \beta_j Strategy_{jit} + \gamma X_{it} + \delta Z_{it} + \varepsilon_{it}$$

where Yit is the agricultural productivity of country i in year t, Strategyjit represents a vector of adaptation and mitigation strategies implemented in country i at time t, Xit includes the climate variables (e.g., temperature, precipitation), Zit encompasses control variables that account for other factors influencing productivity (e.g., technological advancements, economic policies), αi captures the fixed effects for each country or region, and ϵit is the error term.

By dividing the study into these two approaches, we aim to not only understand the multifaceted impacts of climate change on agriculture, but also to highlight practical and effective strategies for resilience and sustainability in Asia's agricultural sector. This structured approach will ensure a comprehensive understanding of the challenges and opportunities presented by climate change, informed by reliable APO data and rigorous analysis.

5. Data

The purpose of this study is to assess the impact of climate change responses in the agricultural sector on agricultural productivity in APO members. For the analysis, data was collected from various international organizations. First, the dependent variable was selected as agricultural labor productivity, which was calculated by dividing GDP by agriculture, hunting, forestry, and fishing at constant prices by employment in agriculture, hunting, forestry, and fishing, and then indexed based on the value of 100 in the base year 2010. The "APO Productivity Databook" and the related "APO Productivity Database," provided by the APO, contain data related to the macroeconomics and productivity of Asian countries, and non-members such as Bahrain, Brunei, China, Kuwait, Myanmar, Qatar, Saudi Arabia, and the United Arab Emirates are included.

This database was developed as part of a joint project between APO, KEO, and Keio University in Tokyo. It covers data on the economic development of Asian countries from 1970 to 2021 and includes projections on economic growth and labor productivity improvements through 2030.

The explanatory variables of this study are meteorological variables of APO countries provided by CRU_CY. To generate the anomaly of climate variables, the calculation method follows the formula suggested by WMO, which subtracts the climate variables of the Reference Period from those of the corresponding year. WMO recommends using the period from 1961 to 1990 as a standard reference period for long-term climate change assessments for this purpose.

The climate change response variables are divided into adaptation and mitigation variables. For climate change adaptation, the study uses data on Vulnerability, Readiness, and Fertilizer consumption. Vulnerability and Readiness were collected from ND-GAIN, and Fertilizer consumption data was collected from USDA. ND-GAIN (Notre Dame Global Adaptation Initiative) provides a database that evaluates a country's vulnerability and adaptation capacity to climate change, contributing to adaptation efforts. Vulnerability refers to the propensity or predisposition of human societies to be negatively impacted by climate hazards. For ease of interpretation, 1 was subtracted from this variable in the analysis. "Readiness" refers to a country's preparedness for investment in adaptation activities, consisting of economic, governance, and social readiness. Fertilizer consumption refers to fertilizer use per hectare of arable land, and this data was sourced from USDA.

For climate change mitigation, agricultural sector CO_2 emissions were collected from Climate Watch, and forest area data was obtained from FAOSTAT through FAO. Carbon tax data from the World Carbon Pricing Database was also collected to apply the status of carbon tax implementation in APO countries to the model.

TABLE 2-5

VARIABLE CONTENTS

Category		Contents	Coverage
Agricultural Productivity		Agricultural Labor Productivity (APO)	1995–2020 20 Selected APO members
Climate		Annual mean temperature anomaly (CRU CY) Annual precipitation anomaly (CRU CY)	1995–2020 20 Selected APO members
Climate Change Response	Adaptation	Stability (ND-GAIN), Readiness (ND-GAIN), Fertilizer consumption (USDA)	1995–2020 20 Selected APO members
	Mitigation	CO_2 emissions by agricultural sector (Climate Watch), Forest area (FAO), Carbon tax (World carbon pricing database)	1995–2020 20 Selected APO members

Source: CFU, https://climatefundsupdate.org/

6. Results

6.1 The direct impacts of climate change on agricultural productivity

In this study, weather anomaly, defined as the difference between the average weather value from 1961 to 1990 and the actual weather value for each year, was used. A growing gap in weather anomalies indicates an increasing divergence between positive and negative values compared to past average weather. To account for the effects of both positive and negative anomalies, a squared variable was applied to the independent variable. This approach enables the study to capture the non-linear impacts of climate variability on productivity, recognizing that even slight deviations from optimal conditions can lead to significant changes in agricultural output. By using the squared variable, the study examines how increasing the magnitude of weather anomalies, whether positive or negative, exacerbates the effects on productivity, illustrating the threshold nature of agricultural responses to climate shocks.

In this context, the unique characteristics of agriculture were considered. Agriculture, being highly climate-sensitive, is most productive at optimal levels of temperature and precipitation. Any deviation, whether an increase or decrease, can result in a decline in yields, thus affecting overall agricultural productivity. This is particularly critical given that agriculture in many Asian countries often operates near such optimal thresholds due to regional climatic and environmental factors.

When temperature rises or falls by 1 degree from the average, agricultural productivity decreases by 0.3%. This suggests that if the historical average represents the optimal climate conditions for a country's agricultural output, larger positive or negative anomalies can disrupt production, leading to reduced productivity. Interestingly, rainfall anomalies were not statistically significant in affecting agricultural productivity, possibly reflecting the region's greater capacity to adapt to rainfall variability through measures such as irrigation infrastructure. This finding underscores the more immediate and profound sensitivity of agricultural productivity in Asian countries to temperature changes, emphasizing the need for adaptation strategies that specifically address temperature-related risks in the face of increasing climate variability.

TABLE 2-6

THE DIRECT IMPACTS OF CLIMATE CHANGE ON AGRICULTURAL PRODUCTIVITY (APO)

	M1	M2	M3
Annual average temperature anomalies squared	-0.003** (-3.62)	-0.003** (-3.66)	-0.003* (-2.54)
Annual precipitation anomalies squared			0.000* (2.72)
Constant	0.018*** (26.91)	0.022*** (23.43)	0.018*** (8.82)
Country effects	Yes	Yes	Yes
Control variable	No	Yes	Yes
Observations	969	969	969
R^2	0.026	0.001	0.005

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.2 Identifying effective adaptation and mitigation strategies

An analysis of climate change strategies, categorized into adaptation and mitigation policies, revealed that adaptation policies had a positive effect on agricultural productivity, while mitigation policies negatively impacted agricultural productivity. The findings indicated that agricultural productivity benefited significantly from greater climate stability, with this relationship being statistically significant. Furthermore, although the increase in fertilizer consumption was marginal, it still positively influenced agricultural productivity. Climate stability was measured by subtracting 1 from the vulnerability index, with improved stability signifying a reduction in sensitivity to extreme weather events or climate change. Consequently, as the negative sensitivity of the agricultural sector to weather conditions or climate change decreases, agricultural productivity is expected to improve.

These findings carry important implications for agricultural policy and climate resilience. The positive impact of adaptation policies on productivity highlights the need for investment in climate-resilient agricultural practices, such as improved irrigation, climate-adaptive crops, and enhanced weather forecasting. The significant role of climate stability in boosting productivity further underscores the importance of reducing climate variability through infrastructural and policy measures aimed at mitigating extreme weather effects. Additionally, the marginal but positive effect of increased fertilizer use suggests the potential for careful nutrient management to enhance yields while avoiding environmental degradation. Overall, these results suggest the importance of integrated climate strategies that support both agricultural productivity and long-term sustainability, ensuring food security in the face of climate change.

On the other hand, the analysis showed that agricultural productivity declined as part of mitigation policies, particularly with the expansion of forest areas and the imposition of carbon taxes. The increase in forested land can be interpreted as a reduction in available farmland, which in turn may negatively affect agricultural output. Moreover, carbon taxes, aimed at curbing high-carbon-emitting agricultural practices, could impose constraints on certain farming activities, thereby further reducing productivity.

These findings imply a potential trade-off between environmental sustainability goals and agricultural productivity. While expanding forest areas and implementing carbon taxes are crucial for achieving long-term climate goals, these measures may inadvertently compromise agricultural output, particularly in regions highly dependent on agriculture for economic stability and food security. Policymakers must therefore consider strategies that balance mitigation efforts with the need to sustain agricultural productivity, such as promoting low-carbon farming technologies or integrating agroforestry practices that enhance both carbon sequestration and crop production. Additionally, targeted subsidies or incentives may be necessary to support farmers in transitioning to more sustainable practices without compromising their livelihoods.

TABLE 2-7

THE IMPACT OF CLIMATE CHANGE RESPONSE POLICIES ON AGRICULTURAL PRODUCTIVITY (APO)

	M1	M2	M3	M4	M5	M6
Adaptation						
Stability	**7.399***** -2.41	**8.439***** -2.95	**6.753***** -2.35	**6.344***** -2.21	**6.212***** -2.13	**-1.467** (-0.50)
Readiness		-1.736 (-0.69)	0.127 -0.13	0.14 -0.14	0.246 -0.25	-0.777 (-0.74)
Fertilizer consumption			**0.001***** -16.17	**0.001***** -15.89	**0.001***** -15.63	**0.001***** -14.01
Mitigation						
Forest area				**-0.027*** (-2.00)	**-0.027*** (-2.06)	-0.015 (-1.35)
Carbon Tax					-0.176 (-1.04)	**-0.409**** (-2.39)
Constant	-3.462** (-2.15)	-3.379 (-2.01)	-3.398** (-2.28)	-2.771* (-1.78)	-2.744* (-1.75)	1.678 -0.94
Year effects	No	No	No	No	No	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	468	468	465	465	465	465
R^2	0.186	0.223	0.596	0.602	0.606	0.679
Adjusted R^2	0.179	0.215	0.59	0.596	0.599	0.655

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The analysis of Asian countries, segmented into high-income and low- to middle-income groups, revealed differing impacts of climate change policies on agricultural productivity. In high-income countries, readiness for climate change had a statistically significant and positive effect on agricultural productivity, indicating that higher levels of preparedness lead to enhanced productivity in these nations. However, in low- and middle-income countries, readiness was not statistically significant, suggesting that the existing level of investment in adaptation remains insufficient to yield measurable productivity gains. In contrast, climate stability had a significant and positive effect on agricultural productivity in low- and middle-income countries, while no such effect was observed in high-income nations. This finding implies that for low- and middle-income countries, enhancing agricultural productivity may be more effectively achieved by focusing on climate stability rather than solely on preparedness, which plays a more crucial role in high-income countries.

These results carry significant policy implications. For low- and middle-income countries, prioritizing investments in infrastructure that mitigates the effects of climate variability, such as flood control, drought management systems, and sustainable water usage, could lead to more immediate gains in agricultural productivity. This highlights the importance of context-specific policy designs, where strategies for improving agricultural resilience must consider the unique economic and climatic conditions of each income group. In high-income countries, continued emphasis on readiness for climate change is crucial, as it has proven to positively impact agricultural productivity, but in lower-income countries, addressing fundamental issues of climate variability and stability may yield more effective results in the short to medium term.

The analysis also found that climate change mitigation policies had divergent impacts on agricultural productivity across income groups. In high-income countries, mitigation policies, such as forest area expansion, had mixed effects, and the imposition of carbon taxes was associated with a negative effect on agricultural productivity. Conversely, in low- and middle-income countries, mitigation policies had a positive impact on productivity, possibly due to the adoption of sustainable practices. However, carbon taxes negatively affected agricultural productivity in both income groups, with the adverse effects being more pronounced in low- and middle-income countries. This stronger negative impact in lower-income nations could reflect their greater reliance on carbon-intensive agricultural methods and limited capacity to transition to greener technologies. Therefore, mitigation policies must be carefully tailored to balance environmental objectives with economic and agricultural productivity, particularly in vulnerable, lower-income regions.

TABLE 2-8

COMPARISON OF HIGH- AND MIDDLE-LOW-INCOME GROUPS

	High-income group			Middle-low-income group		
	M1	M2	M3	M4	M5	M6
Adaptation						
Stability	7.367 (1.58)	6.187 (1.25)	6.753*** -2.35	**4.833***** (4.79)	**4.857***** (3.91)	**5.805*** (1.95)
Readiness	**2.258**** (3.06)	**2.277**** (2.79)	0.412 (0.79)	-2.093 (-1.50)	-1.927 (-1.55)	-1.794 (-1.54)
Fertilizer consumption	0.000 (0.44)	-0.000 (-0.15)	**-0.000** (-0.16)	**0.001***** (14.55)	**0.001***** (17.35)	**0.001***** (24.06)
Mitigation						
Forest area		**-0.039**** (-2.99)	**-0.014**** (-2.74)		0.069 (1.42)	**0.076**** (2.51)
Carbon Tax		-0.183 (-1.81)	**-0.490***** (-7.78)		**-0.602***** (-5.35)	**-0.779***** (-6.16)
Constant	-4.731* (-2.03)	-3.187 (-1.17)	1.604 (0.69)	-1.074 (-1.16)	-1.583 (-1.84)	-2.239 (-1.53)
Year effects	No	No	Yes	No	No	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	257	257	257	208	208	208
R^2	0.570	0.606	0.783	0.730	0.749	0.789
Adjusted R^2	0.559	0.593	0.751	0.722	0.739	0.749

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Countries classified as High and Upper-middle-income include IDN, IND, JPN, KHM, KOR, LAO, LKA, MNG, PHL, THA, TUR and Lower-middle-income include BGD, FJI, IRN, MYS, NPL, PAK, SGP, VNM.

The analysis indicated that while precipitation anomalies do not have a direct effect on agricultural productivity, the impact of climate change adaptation and mitigation policies was differentiated by precipitation levels. When countries were divided into two groups, those with precipitation above the median and those below, it was found that in countries with higher-than-average precipitation, agricultural productivity significantly increased with improved climate stability. This effect was more pronounced than in countries with lower-than-average precipitation.

Interestingly, in high-precipitation countries, even with high levels of climate change preparedness, agricultural productivity experienced a negative impact, whereas in low-precipitation countries, preparedness had a positive effect on productivity. Additionally, the imposition of a carbon tax as a mitigation measure was shown to reduce agricultural productivity in both high- and low-precipitation groups, exacerbating the challenges faced by the agricultural sector.

These findings have important implications for climate policy design. In high-precipitation countries, the focus may need to shift from preparedness to improving stability and resilience, as excessive reliance on preparedness measures alone may not yield the expected gains in productivity. By contrast, low-precipitation countries might benefit more from enhancing preparedness and stability concurrently. Furthermore, the consistent negative impact of carbon taxes on productivity suggests the need for more nuanced and region-specific mitigation strategies that minimize harm to agricultural productivity while promoting environmental sustainability. This could involve offering subsidies or technological support to help farmers transition to lower-emission practices without significantly compromising their output.

TABLE 2-9

COMPARISON OF OVER AND UNDER PRECIPITATION GROUPS

	Precipitation above or equal to the overall median			Precipitation below or equal to the overall median		
	M1	M2	M3	M4	M5	M6
Adaptation						
Stability	**10.449***** (4.16)	**9.559***** (3.79)	-1.408 (-0.30)	**3.942**** (2.62)	**3.878**** (2.95)	3.061 (1.79)
Readiness	-1.779 (-1.15)	-1.658 (-1.19)	**-2.835*** (-1.87)	1.274 (1.75)	1.711 (1.81)	**1.368*** (2.05)
Fertilizer consumption	**0.001***** (11.20)	**0.001***** (12.55)	**0.001***** **(12.98)**	-0.001 (-1.18)	-0.001 (-1.06)	**-0.001*** (-1.91)
Mitigation						
Forest area		-0.031 (-1.55)	-0.021 (-1.01)		-0.093 (-1.31)	-0.080 (-1.11)
Carbon Tax		**-0.611***** (-5.17)	**-0.904***** (-6.13)		**-0.244***** (-4.46)	**-0.353***** (-6.18)
Constant	-4.144** (-2.74)	-3.138 (-1.84)	2.745 (1.26)	-2.583*** (-3.81)	-1.683 (-1.71)	-1.118 (-1.10)
Year effects	No	No	Yes	No	No	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	231	231	231	234	234	234
R^2	0.686	0.710	0.768	0.669	0.695	0.775
Adjusted R^2	0.678	0.700	0.730	0.660	0.684	0.738

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

7. Policy Implications: Adaptation and Mitigation Strategies

This study explored the impacts of climate change on agricultural productivity across APO members, focusing on adaptation and mitigation strategies. The findings highlight the significant challenges climate change poses to agriculture, particularly in relation to temperature anomalies, which negatively affect productivity across the region. However, there are notable differences in how high-income and low- to middle-income countries experience and address these impacts.

In high-income countries, readiness for climate change positively impacts agricultural productivity, indicating that investments in infrastructure, technology, and governance play a crucial role in maintaining productivity under changing climate conditions. Low- and middle-income countries, however, benefit more from investments aimed at stabilizing climate conditions. These countries can significantly enhance productivity by investing in infrastructure such as advanced irrigation systems, flood control, and drought management, which help mitigate the effects of climate variability. The study suggests that adaptation strategies must be context-specific, designed to fit the economic and environmental conditions of each income group.

Mitigation strategies present more complex challenges. Carbon taxes and forest area expansion, although important for reducing greenhouse gas emissions and increasing carbon sequestration, have been associated with reduced agricultural productivity, particularly in low- and middle-income countries. These regions rely more on carbon-intensive agricultural practices and have limited capacity to transition to greener technologies without economic trade-offs. To address this, mitigation policies should balance environmental goals with agricultural productivity needs. Policymakers can promote agroforestry practices, which integrate trees with crops or livestock farming to provide multiple benefits, including carbon sequestration, enhanced biodiversity, and sustained agricultural productivity. Additionally, offering incentives or subsidies for low-carbon technologies in agriculture, such as renewable energy-based farming equipment, precision agriculture tools, and sustainable soil management techniques, can support farmers in making the transition without compromising output.

The policy implications of this study suggest that in low- and middle-income countries, investments should prioritize climate stability. Governments can consider strategies like enhancing water management systems through smart irrigation technologies, promoting climate-resilient crop varieties, and implementing regional disaster preparedness systems to mitigate the effects of floods and droughts. For instance, strategies such as drip irrigation, rainwater harvesting, and the use of drought-tolerant seeds have proven effective in several countries and can be scaled up across the region. Additionally, adopting policies that support crop diversification and the development of sustainable agricultural practices will help reduce the sector's vulnerability to climate shocks.

In high-income countries, where preparedness has shown to be effective, governments should continue investing in climate-resilient infrastructure and policies. Key strategies include expanding research and development into climate-resilient crops, scaling up precision agriculture technologies to optimize resource use, and improving early warning systems for extreme weather events. High-income countries are also better positioned to lead innovation in agriculture, such as adopting robotics and automation for climate-smart farming, which can further enhance productivity under adverse climate conditions.

Mitigation strategies require a nuanced approach to ensure that environmental objectives do not conflict with agricultural productivity. Carbon taxes should be designed with flexibility, allowing for gradual transitions to low-carbon farming practices, possibly by offering tax credits or grants for sustainable farming investments. Agroforestry and regenerative agriculture offer promising pathways to balance productivity with environmental goals. Policies that incentivize the incorporation of tree planting in agricultural landscapes can help sequester carbon while supporting crop production. Moreover, adopting soil conservation practices like no-till farming and cover cropping can improve soil health, reduce emissions, and increase resilience to climate variability.

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Appendix

A1

THE IMPACT OF CLIMATE CHANGE RESPONSE POLICIES ON AGRICULTURAL PRODUCTIVITY ABOUT HIGH -INCOME GROUPS

	M1	M2	M3	M4	M5	M6
Adaptation						
Stability	**9.300*** (1.92)	7.805 (1.57)	7.367 (1.58)	6.417 (1.32)	6.187 (1.25)	-1.774 (-0.47)
Readiness		**2.091**** (2.75)	**2.258**** (3.06)	**2.132**** (2.63)	**2.277**** (2.79)	0.412 (0.79)
Fertilizer consumption			0.000 (0.44)	0.000 (0.00)	-0.000 (-0.15)	-0.000 (-0.16)
Mitigation						
Forest area				**-0.038**** (-2.93)	**-0.039**** (-2.99)	-0.014** (-2.74)
Carbon Tax					-0.183 (-1.81)	-0.490*** (-7.78)
Constant	-4.875* (-1.93)	-4.847* (-2.02)	-4.731* (-2.03)	-3.280 (-1.22)	-3.187 (-1.17)	1.604 (0.69)
Year effects	No	No	No	No	No	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	260	260	257	257	257	257
R^2	0.508	0.573	0.570	0.598	0.606	0.783
Adjusted R^2	0.500	0.565	0.559	0.587	0.593	0.751

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Countries classified as High and Upper-middle-income include IDN, IND, JPN, KHM, KOR, LAO, LKA, MNG, PHL, THA, TUR.

A2

THE IMPACT OF CLIMATE CHANGE RESPONSE POLICIES ON AGRICULTURAL PRODUCTIVITY ABOUT MIDDLE-LOW-INCOME GROUPS

	M1	M2	M3	M4	M5	M6
Adaptation						
Stability	5.074 (1.68)	**6.574***** (4.36)	**4.833***** (4.79)	**4.787***** (3.87)	**4.857***** (3.91)	**5.805*** (1.95)
Readiness		-4.829 (-1.31)	-2.093 (-1.50)	-2.068 (-1.54)	-1.927 (-1.55)	-1.794 (-1.54)
Fertilizer consumption			**0.001***** (14.55)	**0.001***** (14.87)	**0.001***** (17.35)	**0.001***** (24.06)
Mitigation						
Forest area				0.078 (1.52)	0.069 (1.42)	0.076** (2.51)
Carbon Tax					**-0.602***** (-5.35)	**-0.779***** (-6.16)
Constant	-1.655 (-1.00)	-0.619 (-0.35)	-1.074 (-1.16)	-1.562 (-1.80)	-1.583 (-1.84)	-2.239 (-1.53)
Year effects	No	No	No	No	No	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	208	208	208	208	208	208
R^2	0.054	0.300	0.730	0.735	0.749	0.789
Adjusted R^2	0.035	0.283	0.722	0.725	0.739	0.749

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Countries classified as High and Upper-middle-income include IDN, IND, JPN, KHM, KOR, LAO, LKA, MNG, PHL, THA, TUR and Lower-middle-income include BGD, FJI, IRN, MYS, NPL, PAK, SGP, VNM.

A3

THE IMPACT OF CLIMATE CHANGE RESPONSE POLICIES ON AGRICULTURAL PRODUCTIVITY ABOUT PRECIPITATION ABOVE OR EQUAL TO THE OVERALL MEDIAN

	M1	M2	M3	M4	M5	M6
Adaptation						
Stability	**10.189**** (2.93)	**12.705***** (4.36)	**10.449***** (4.16)	**9.487***** (3.86)	**9.559***** (3.79)	-1.408 (-0.30)
Readiness		-4.698 (-1.22)	-1.779 (-1.15)	-1.827 (-1.21)	-1.658 (-1.19)	**-2.835*** (-1.87)
Fertilizer consumption			**0.001***** (11.20)	**0.001***** (11.45)	**0.001***** (12.55)	**0.001***** (12.98)
Mitigation						
Forest area				-0.031 (-1.55)	-0.031 (-1.55)	-0.021 (-1.01)
Carbon Tax					**-0.611***** (-5.17)	**-0.904***** (-6.13)
Constant	-4.333* (-2.27)	-3.937* (-1.94)	-4.144** (-2.74)	-3.036 (-1.78)	-3.138 (-1.84)	2.745 (1.26)
Year effects	No	No	No	No	No	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	234	234	231	231	231	231
R^2	0.101	0.303	0.686	0.697	0.710	0.768
Adjusted R^2	0.085	0.288	0.678	0.687	0.700	0.730

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A4

THE IMPACT OF CLIMATE CHANGE RESPONSE POLICIES ON AGRICULTURAL PRODUCTIVITY ABOUT PRECIPITATION BELOW OR EQUAL TO THE OVERALL MEDIAN

	M1	M2	M3	M4	M5	M6
Adaptation						
Stability	4.278* (1.98)	3.226* (1.95)	3.942** (2.62)	4.100** (2.93)	3.878** (2.95)	3.061 (1.79)
Readiness		1.608* (1.95)	1.274 (1.75)	1.532 (1.63)	1.711 (1.81)	1.368* (2.05)
Fertilizer consumption			-0.001 (-1.18)	-0.001 (-0.78)	-0.001 (-1.06)	-0.001* (-1.91)
Mitigation						
Forest area				-0.085 (-1.18)	-0.093 (-1.31)	-0.080 (-1.11)
Carbon Tax					-0.244*** (-4.46)	-0.353*** (-6.18)
Constant	-2.422* (-2.26)	-2.434** (-2.88)	-2.583*** (-3.81)	-1.831 (-1.83)	-1.683 (-1.71)	-1.118 (-1.10)
Year effects	No	No	No	No	No	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	234	234	234	234	234	234
R^2	0.604	0.660	0.669	0.677	0.695	0.775
Adjusted R^2	0.597	0.653	0.660	0.667	0.684	0.738

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

CLIMATE CHANGE ON MANUFACTURING PRODUCTIVITY AND POLICY IMPLICATIONS

1. Introduction

In recent years, the patterns of climate change have become increasingly evident and alarming. Global temperatures are rising at an unprecedented rate, leading to more frequent and severe weather events such as hurricanes, heatwaves, and heavy rainfall. The polar ice caps are melting faster than ever, contributing to rising sea levels and threatening coastal communities. These changes are not uniform across the globe; some regions are experiencing more intense droughts and wildfires, while others are facing increased flooding and storms. Additionally, climate change is disrupting ecosystems and biodiversity, leading to shifts in species distributions and threatening the survival of many plants and animals. Human activities, particularly the burning of fossil fuels and deforestation, are the primary drivers of these changes, emphasizing the urgent need for global cooperation and action to mitigate the impacts and adapt to a rapidly changing environment.

Climate change affects various sectors of the economy, with its impacts being felt differently across regions and industries. For example, Intergovernmental Panel on Climate Change (IPCC) reports that average temperature has constantly increased all over the world, but the gain is different across continents and regions. Climate change and natural disasters incur social costs such as uncertainty, unrest, and an increase in diseases, and thus affect investment, industrial structure, productivity, and economic growth. However, these social costs depend on what industries are applied, such as agriculture and manufacturing. Manufacturing will be differently affected by climate change, depending on its characteristics of technological intensity, response skill and working conditions. The manufacturing sector in the APO member economies is also subject to significant transformations due to these changes. It is expected that climate change has affected productivity in manufacturing industries of APO member economies, depending on their characteristics such as an income level and climatic adaptation technique.

The main objective of this chapter is to empirically examine the effects of climate change on the manufacturing productivity of APO member economies during the 1970–2021 period, focusing on how different environmental factors influence economic outcomes, and provide policy implications for climate change and environment. Along with analyses for the whole sample dataset, I decompose the entire countries into developed and developing countries, the entire sample period into the 1970–1989, the 1990–2009 and the 2010–21 periods, and climate change into air temperature and precipitation. For proxies for climate change, I consider the levels of temperature and precipitation anomalies, respectively, representing departures from reference values or long-term averages.

The direct impacts of climate change are most evident in the agricultural sector, where changes in temperature and precipitation patterns directly affect crop yields and livestock production. These changes can lead to shifts in comparative advantage and the reallocation of resources between sectors, thereby indirectly affecting the manufacturing sector. For instance, a decrease in agricultural productivity may lead to an increased reliance on imported raw materials, which can raise production costs for manufacturers. Conversely, an increase in agricultural output can enhance the productivity of related industries, demonstrating the interconnectedness of these sectors. Meanwhile, climate change can directly affect the manufacturing sector. For example, extreme weather events such as heatwaves, floods, typhoons, and large-scale wildfires further complicate the economic landscape. These events not only disrupt production processes but also pose significant risks to the health and well-being of workers. The health impacts, including heatstroke, cardiovascular diseases, and the spread of infectious diseases like malaria and dengue fever, can reduce labor productivity and increase healthcare costs. These factors underscore the importance of adaptive capacity, including technological advancements and robust social infrastructure, in mitigating the adverse effects of climate change.

Moreover, the economic impact of climate change varies significantly depending on the industrial structure and adaptive capacities of different countries. Developing economies in particular may face more severe negative effects due to limited resources and technological capabilities. The manufacturing sector, which often includes both labor-intensive and capital-intensive industries, is particularly sensitive to these changes. Indoor work environments, common in manufacturing, are directly influenced by the availability and efficiency of heating and cooling systems, highlighting the importance of corporate adaptability.

Future international response policies for climate change must focus on enhancing the technological, educational, and infrastructural capacities of developing countries. Such measures will enable these economies to better adapt to environmental changes and maintain economic stability. This chapter will utilize various variables and analytical methodologies to explore these dynamics, providing valuable insights into the policy implications for APO member economies. By understanding the multifaceted impacts of climate change on manufacturing productivity, this chapter aims to contribute to more informed and effective policymaking, ultimately supporting sustainable economic growth in the face of environmental challenges.

This chapter proceeds as follows. Section 2 reports the trends of manufacturing in APO member economies, focusing on its share in GDP and labor productivity. Section 3 investigates previous studies to build up the theoretical background for empirical analyses. Section 4 introduces the econometric specifications and data employed in this chapter. Section 5 presents the empirical results. Finally, section 6 summarizes the findings and makes concluding remarks with policy implications.

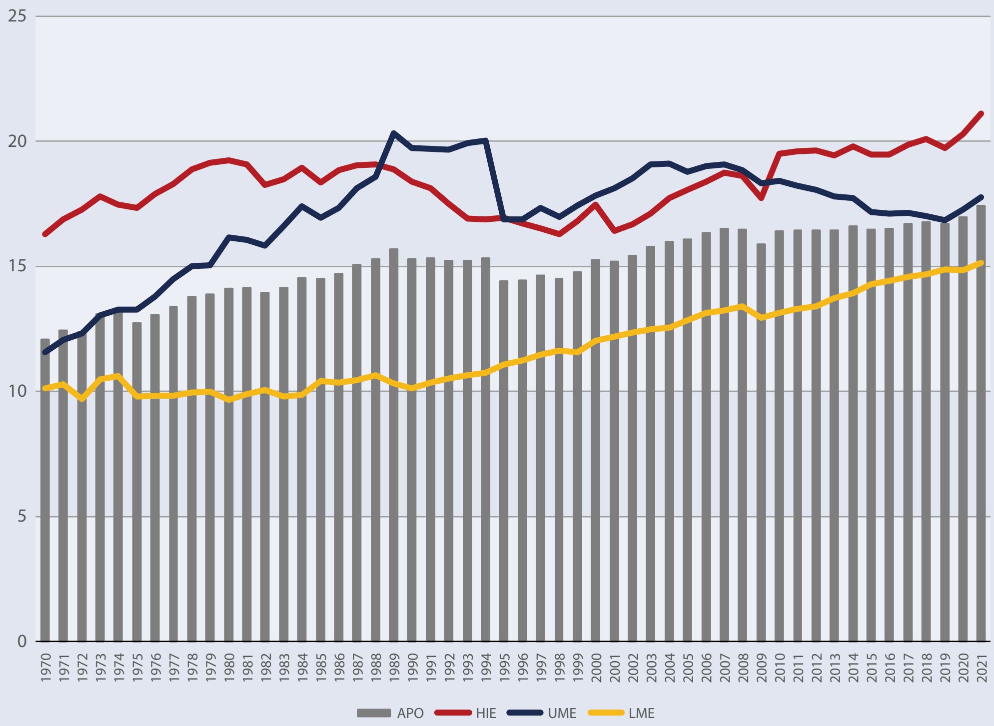
2. Trends of Manufacturing in APO Member Economies

2.1 Manufacturing Share in GDP

Figure 3-1 depicts the trends of the average manufacturing sector's share in GDP for entire APO members, and high, upper-middle, and lower-middle income members, respectively. The figure shows that the average manufacturing sector's share of high-income members was greater than that of the others during the 1970s and 1980s, but upper-middle income members beat high income members during the 1990s and 2000s. After that, high income members recaptured a first position during the 2010s and early 2020s, while upper-middle income members went down. For lower-middle income members, the average manufacturing sector's share maintained a constant level during the 1970's and 1980s, but has started increasing since 1990. The gap among members has been rapidly narrowed since the 2000s.

FIGURE 3-1

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021



Note: APO (Entire APO members), HIE (High-income APO members), UME (Upper-middle income APO members), LME (Lower-middle income APO members)
Source: Author's calculations based on the APO Productivity Database

Table 3-1 ranks APO member economies by their manufacturing sector's share in GDP of 2021. The table shows that the highest-ranking economy is the Republic of China (ROC) (35.75%), followed by the ROK (27.26%), Thailand (26.97%), and Vietnam (24.45%). In 2021, most of the high-ranking positions are upper-middle economies although high income economies take the first and the second positions.

TABLE 3-1

RANKING BY AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP OF 2021 (%)

Order	Member	Ratio	Order	Member	Ratio
1	ROC	35.76	12	Turkiye	16.91
2	ROK	27.26	13	Sri Lanka	16.64
3	Thailand	26.97	14	Cambodia	14.39
4	Vietnam	24.25	15	India	13.17
5	Malaysia	23.45	16	Fiji	12.38
6	Bangladesh	23.14	17	Pakistan	11.11
7	Singapore	21.29	18	Lao PDR	8.919
8	Japan	20.33	19	Mongolia	7.961
9	Indonesia	19.6	20	Nepal	5.362
10	Philippines	19.2	21	Hong Kong	1.02
11	I.R. Iran	17.1			

Source: Author's calculations based on the APO Productivity Database

Figure A1 in the appendix show the trend of the share of manufacturing in GDP for each member economy from 1970 to 2021. Generally, the manufacturing sector's share in GDP has shown various trends: some countries might experience a rise due to industrialization and economic growth, while others might see a decline as economies transition towards agriculture and services sectors.

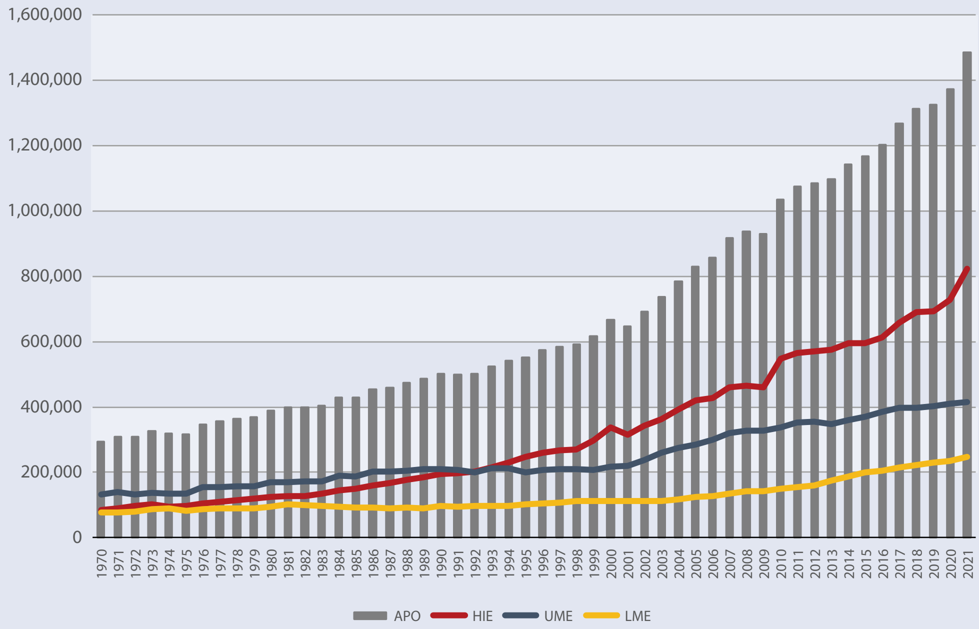
2.2 Labor Productivity in Manufacturing

Figure 3-2 depicts the trend of average labor productivity in manufacturing for entire APO members, and high, upper-middle, and lower-middle income members, respectively. In general, the average labor productivity in manufacturing sector in APO member economies is on an increasing trend from 1970 to 2021. However, there are some differences in trends among high, upper-middle, and lower-middle income members: the average labor productivity in manufacturing sector in upper-middle income members was greater than that of the others during the 1970s and 1980s, but high income members beat upper-middle income members after 1992 with a rapid increase. After that, the gap between high income members and others has widened, and this gap is greatest in 2021. For lower-middle income members, the average labor productivity maintained a constant level from the 1970s to 2000s, but is showing a slight upward trend during the 2010s.

Considering the results from figures 3-1 and 3-2 together, in terms of scale in manufacturing production, the gap has narrowed among high, upper-middle, and lower-middle income members since 2000's. However, in terms of quality in manufacturing production, the gap has widened among these groups since 2000's. Accordingly, the results of figures 3-1 and 3-2 imply that the entire sample period should be divided into three periods of the 1970s and 1980s (1970–89), the 1990s and 2000s (1990–2009), and the 2010s and early 2020s (2010–21) in the regression analyses.

FIGURE 3-2

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021



Note: APO(Entire APO members), HIE(High-income APO members), UME(Upper-middle income APO members), LME(Lower-middle income APO members)
Source: Author's calculations based on the APO Productivity Database

Table 3-2 ranks APO member economies by their labor productivity in manufacturing in 2021. The table shows that the highest-ranking economy is Singapore (USD328,098), followed by the ROC (USD170,370), the ROK (USD155,331), and Japan (USD115,052) and thereby, most of the high-ranking positions are high income economies in 2021. Consequently, tables 3-1 and 3-2 also imply that in manufacturing production of APO member economies, upper-middle income members have the advantage in terms of scale, while high income members have it in terms of quality.

TABLE 3-2

LABOR PRODUCTIVITY IN MANUFACTURING SECTOR OF 2021 (USD)

Order	Member	Value	Order	Member	Value
1	Singapore	328,098	12	Mongolia	40,522
2	ROC	170,370	13	Indonesia	39,733
3	ROK	155,331	14	Sri Lanka	39,074
4	Japan	115,052	15	Lao PDR	34,014
5	Turkiye	86,938	16	Bangladesh	24,679
6	Malaysia	85,758	17	Vietnam	24,046
7	Philippines	65,770	18	India	23,790
8	Thailand	61,044	19	Pakistan	15,561
9	I.R. Iran	58,421	20	Cambodia	13,745
10	Hong Kong	54,748	21	Nepal	6,636
11	Fiji	42,065			

Source: Author's calculations based on the APO Productivity Database

Figure A2 in the appendix shows the trend of average manufacturing productivity in the manufacturing sector for each member economy from 1970 to 2021. Variations in trends across countries could reflect differences in economic policies, investment in technology and education, and industrial focus.

3. Theoretical Background and Literature Review

3.1 Mechanisms on Climate Change and Economic Performances

In most cases, previous studies found that climate change has a negative impact on the economy through the channel of changes in health, natural, social, political, structural environments.[10] Above all, climate change directly deteriorates health conditions and well-being of workers, increases the chances of error, injury or death, and therefore decreases their productivity. Through this, climate change indirectly affects the entire economy, including manufacturing sectors. World Economic Forum (2023a) addressed the five key health impacts of climate-related hazards: heat-related ill-health such as fatigue, exhaustion, food poisoning, and heatstroke; respiratory illness such as hay fever and asthma; physical and psychological toll; diseases from an increase in insects such as malaria and dengue fever; and pesticide-related impacts such as the toxic chemicals.[11]

Also, extreme weather events and natural disasters such as heat waves, floods, droughts, typhoons, hurricanes, earthquakes, and large-scale wildfires due to climate change affect changes in global environment such as flora and fauna ecosystems and rising sea levels, and therefore also damage crops, livestock, and human malnutrition and mental disorder (Burton et al. 1993). In addition to deterioration in health and natural environments, climate change negatively affects social and political environments. For African countries, Luber and McGeehin (2008) and Weitzman (2009) showed that lack of rainfall induced conflicts between tribes or countries over securing drinking

10 Refer to Tol (2009) and Lai et al. (2023) for meticulous literature review for the relationship between climate change and economic performances.

11 Also refer to the following papers for deterioration of health conditions and disease environment from climate change: Luber and McGeehin (2008), Ramsey et al. (1998), Rooney et al. (1998), Huynen et al. (2001), Wlokas (2008), Auld et al. (2010), Masahiro et al. (2010), McMichael and Lindgren (2011), and Kjellstrom et al. (2019).

water, frequent regime changes, and civil wars. These political and social instabilities decreased gross national productivity.

Climate change also has a negative impact on the formation of industrial infrastructures, such as a decrease in power supply (Magadza 1996), capital depreciation (Acevedo et al. 2020), and damages to business assets and transport routes (World Economic Forum 2023a). Lower productivity and greater absenteeism from deteriorations in health, natural, social and political environments and damages to industrial infrastructures by climate change all influence the output of factories in manufacturing and the economy as a whole (Somnathan et al. 2021). Especially, outdoor work sites such as construction and indoor manufacturing environments lacking adequate air conditioning increase fatigue and reduce concentration among workers (Kjellstrom et al. 2019).

In some cases, climate change can also have positive impacts on the economy. Climate change leads to the demand of cooling equipment and energy consumption in manufacturing and mining sectors, and an increase in tourism, leisure, recreational services, and demand for healthcare in service sectors (Ceron and Dubois 2005, Hamilton et al. 2005, Agnew and Viner 2001, Belle and Bramwell 2005). World Economic Forum (2023b) addressed that the global transition to sustainable energy, as well as climate change adaptation, are expected to be net job creators. Climate change can improve the function of infrastructures. For example, the increase in rainfall can improve water supply and thereby enhance power supply. This improvement of social infrastructure can lead to an increase in agricultural and manufacturing productions (Deschênes and Greenstone 2007). These increases in production of specific sectors also lead to an increase in that of related sectors, and the positive effects will potentially spread across industries through this industrial linkage effect. For example, an increase in agricultural production by climate change can lead to an increase in related industries in manufacturing such as farm machines and fertilizer. Even a decrease in agricultural production by climate change can lead to an increase in manufacturing production through the reallocation of production factors between industries, according to the Heckscher-Ohlin model (Albert et al. 2021).

3.2 Empirical Evidences on Climate Change and Economic Performances

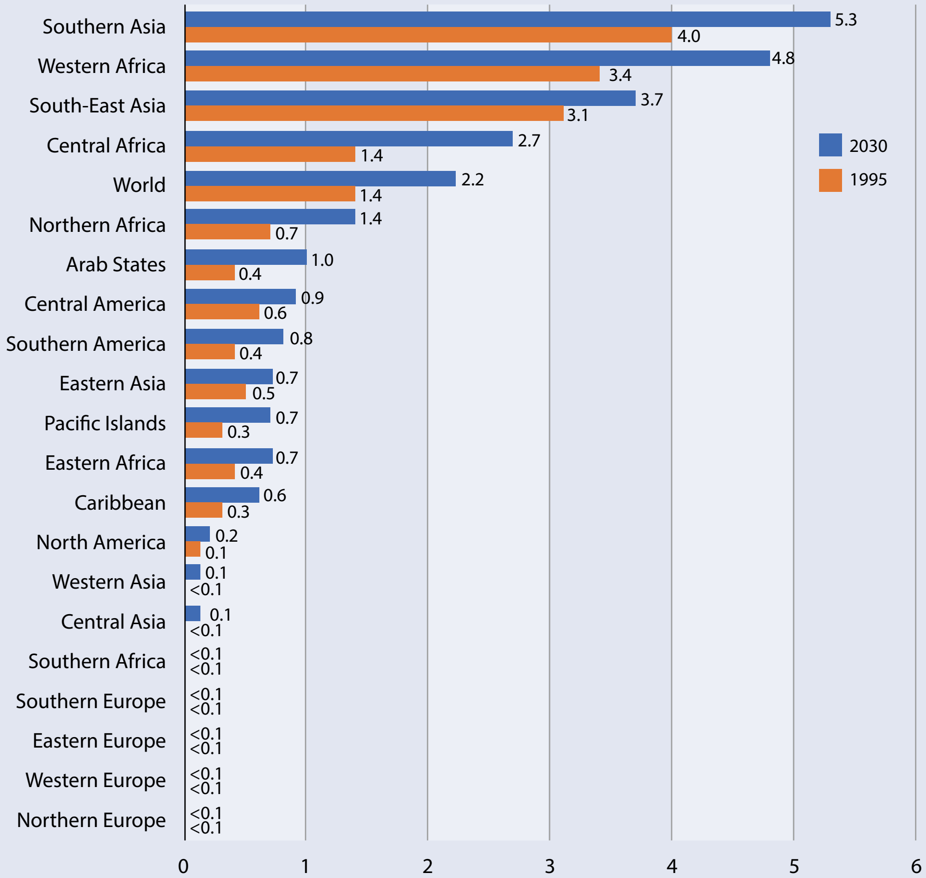
Many previous studies empirically examined the effects of climate change on aggregate economic performances, such as GDP and national productivity for multiple countries. For example, Horowitz (2009) empirically examined how the increase in temperature affected 100 countries' income, considering colonial mortality rates as a proxy for countries' average temperature in Latin America for the early 19th century to capture the historical pathway for temperature. Using the cross-sectional regressions, Horowitz (2009) showed that a 1°C increase in temperatures across all countries caused a decrease of 3.8% in world GDP. Targeting for subnational regions for 30 years, Dasgupta et al. (2021) found that climate conditions negatively affected labor effectiveness that consists of labor forces, the number of hours worked, and the productivity of workers. For projected impacts of future climate change, they predicted that global labor effectiveness would decrease by 18–24.8%p under a scenario of 3.0°C warming. Similarly, Kjellstrom et al. (2019) simulated the effects of global warming on labor productivity and expected that more than 2.2% of total working hours worldwide would be lost every year by 2030.

Meanwhile, previous studies showed that the effects of climate change on aggregate economic performances were different across countries' characteristics, especially their income. Using panel analyses, Dell et al. (2008) empirically examined the effects of annual variation in temperature and precipitation on economic growth in 136 countries during the 1950–2006 period and showed that higher temperature had substantial negative effects on economic growth rates in low-income countries, but little effects in high-income countries: a 1°C increase in temperature reduced low-income countries' GDP by about 1.1%, while its effects on the world's GDP were negligible. In low-income countries, higher temperature had negative effects on various economic performances such as agricultural and industrial outputs, aggregate investment, and political stability. Similarly, using the meta-analysis of literature review, Mendelsohn and Dinar (1999) focused on developing countries and found adverse effects of global warming on their economic development and welfare, because they depended heavily on agriculture. However, their empirical results for India and Brazil showed that farmers' ability to adapt to local climate changes mitigated these negative effects. Meza and Silva (2009) also addressed the role of farmers' adaption to climate change. Acevado et al. (2020) found that low-income countries suffered the largest costs from climate change: aggregate output and investment were about 2% and about 10% lower for seven years, respectively, after a 1°C increase in average annual temperature. Accordingly, they concluded that economic development would help shield countries from temperature shocks.

For specific regions and countries, Barrios et al. (2010) focused on sub-Saharan African countries over the 1960–90 period and empirically showed that rainfall was a significant factor for decreasing economic growth in African countries, but not for other countries. In the scenario of no decline in rainfall, they estimated that the gap in per capita GDP between African countries and Latin American and Caribbean countries would decrease by 15–40%. Kjellstrom et al. (2019) predicted that labor productivity would decrease by about 2.2% every year by 2030 due to global warming, which in turn would harm aggregate economic growth. Also, they showed that this phenomenon would be more prominent in low-income regions such as Southern Asia, Western Africa, Southeast Asia, and Central Africa (see figure 3-3). Dasgupta et al. (2021) found that there were more prominent negative effects of climate change on labor effectiveness in tropical countries. For future climate change, they predicted that total labor effectiveness would decrease by 25.9%p in Africa, 18.6%p in Asia, and 10.4%p in Americas under the scenario of 3.0°C warming. Consequently, they addressed that parts of sub-Saharan Africa, South Asia, and Southeast Asia would be at highest risk under future global warming. Kumar and Maiti (2024) focused on 21 emerging economies over the 1990–2018 period and showed that on average a 1°C increase in temperature decreased TFP by about 3.22% and this negative effect was much higher in less developed economies and extreme climatic zones. Hence, even in developing countries, climate change can affect productivity heterogeneously across countries, depending on their climatic zones and income levels.

FIGURE 3-3

WORKING HOURS LOST TO HEAT STRESS BY SUBREGION, 1995 AND PROJECTIONS FOR 2030 (PERCENTAGES)



Source: Kjellstrom et al. (2019, p.24)

For agricultural production, most previous papers found negative effects from climate change. Especially, ecosystem changes by climate change affected a decrease in agricultural productivity (Nicholson 1994). Ortiz-Bobea et al. (2021) showed that climate change had reduced global agricultural productivity by about 21% since 1961. Huang et al. (2020) showed that climate change disproportionally damaged to marginal returns to labor across sectors in 279 rural communities in China during the 2010–12 period: a 1°C increase in temperatures will decrease an average rural resident's agricultural work time by 7.0%, but increase non-agricultural work time by 7.8%.[12] More specifically, Albert et al. (2021) focused on the relationship between climate change and a reallocation of production resources in Brazil during the 2000–10 period, based on theories of comparative advantage and disadvantage in classical international trade and geography models. They showed that labors in drying regions reallocated from agriculture to manufacturing as climate change reduced agricultural productivity in developing countries, while capital reallocation did not happen.

12 They also found differential responses to climate change across gender, showing that higher temperatures mainly shifted males' time from leisure to non-agricultural work, but females' time from agricultural work to non-agricultural work.

However, some papers conversely found positive effects of climate change on agricultural production. For example, Deschênes and Greenstone (2007) showed that the random year-to-year variation in temperature and precipitation increased annual profits by USD1.3 billion in 2002, or 4% in U.S. agriculture. For agricultural TFP in China over the 2000–21 period, Shah et al. (2004) showed that eight out of nine regions witnessed negative effects of climate change as expected, but one region witnessed positive effects due to higher production technology. Similarly, Bai et al. (2022) showed that climate change hindered agricultural productivity growth only in the western region of China, but did not affect it in the eastern and central regions. IPCC (2007) addressed that it is difficult to determine the overall trend of agricultural output changes due to climate change because it can promote agricultural output, but simultaneously spread pests and diseases and change suitable cultivation areas.

Several papers empirically examined that the effects of climate change on economic performances can be different across sectors. Dasgupta et al. (2021) divided all sectors into low-exposure (i.e., indoors or outdoors in the shade) and high-exposure (i.e., outdoors in the sun) ones and found that the negative effects of global warming on labor effectiveness would be more prominent for outdoors in full sunlight. Similarly, Schleypen et al. (2021) and Garcia-leon et al. (2021) found that heat impacts on labor productivity were largest in outdoor sectors in Europe.

The effects of climate change on economic performances can depend on methodologies and proxies. For example, Choi and Park (2015) empirically examined the effects of climate change on national TFP of 83 countries during the 1990–2010 period, considering maximum values of temperature and precipitation, as well as their average values. Their results imply that the effects of climate change on productivity can vary depending on econometric specifications such as proxies and regression methodologies. On the one hand, their results from ordinally least squares (OLS) showed that average temperature negatively affected TFP, as expected. However, the increase in maximum temperature positively affected TFP because the increase in agricultural productivity offset the decrease in other sectors' productivity. Also, they addressed that the increase in maximum temperature could positively affect overall industry by promoting demand of air conditioners, energy consumption, tourism and leisure services. Meanwhile, they showed that average precipitation could promote overall industry productivity because water supply could enhance an electric power supply. However, the increase in maximum precipitation negatively affected overall industry's productivity by increasing risk factors such as floods. On the other hand, in their panel analyses, the results showed that average temperature positively affected TFP. Consequently, they concluded that countries effectively corresponded to climate change, and therefore adoptable capacity would be important to forecast its effects on economies. Several studies also supported this argument, such as Mendelsohn and Dinar (1999) for India and Brazil and Wlokas (2008) for Southern Africa.

Compared to agriculture and service industries, fewer studies have analyzed the effects of climate change on manufacturing or non-agricultural sectors. Many of these studies focused on a few individual countries, hence providing only limited variations in terms of both the impact of temperature changes on productivity and variations across countries by income and geography. Choi and Park (2016) empirically examined the effects of climate change on Korean manufacturing productivity over the 2000–12 period and showed that the effects of temperature and precipitation on manufacturing production were statistically insignificant, regardless of econometric methodologies. For these results, they observed that most manufacturers were operated by an indoor working process and most companies had their own cooling and heating systems well in the

ROK and therefore addressed that firms' adoptable capacity to climate change would be very important for a change in manufacturing productivity, especially working in an indoor environment, in response to gradual climate change. Kassa and Woldemichael (2024) empirically examined the impacts of climate change on firm-level productivity with the survey data of nonagricultural firms in 154 countries over the 2006–22 period and showed that an increase in temperatures negatively affected productivity overall, but nonlinear and uneven across climate zones. Interestingly, they found that firms in hotter zones experienced steeper losses in response to an increase in temperature: a 1°C increase in the typical wet-bulb temperature levels in the hottest climate zone resulted in a decrease in productivity by about 20.8%, compared to firms in the coolest climate zone.

For the United States, Park (2017) focused on non-agricultural outputs in 3,000 U.S. counties over the 1986–2012 period and showed that hot temperature exerted a significant causal impact on local labor product and this effect was more prominent in highly exposed industries such as construction, manufacturing, and transportation. Park (2017) estimated that additional 10 days above 90°F in a year would reduce output per capita in highly exposed sectors by 1.3–3.5%. Similarly, Deryugina and Hsiang (2014) focused on U.S. counties over a 40-year period and showed that productivity on an individual day declines by 1.7% for each 1°C increase in daily average temperature above 15°C. They estimated that a weekday above 30°C would cost USD20 per person in an average county and an increase in daily temperatures would lower annual growth by 0.06–0.16%p in the United States, unless populations engaged in new forms of adaptation.

For firms in Chinese metal industrial chain over the 2008–18 period, Zou and Zhong (2022) found that a day with average temperature above 90°F was associated with TFP loss of 0.56%, relative to a day with average temperature between 50°F and 60°F. Chen et al. (2023) focused on 35,190 Chinese workers' productivity in a high-technology and precision manufacturing sectors and showed that an increase in wet bulb temperature of 10°C caused a reduction in output of 8.3%. These results imply that climate change can harm productivity even though workspaces are indoors and protected by high-quality climate control systems.

For manufacturing firms and workers in India over the 1998–2009 period, Somanathan et al. (2021) showed that annual plant output fell by about 2% per an 10°C increase in temperatures. Interestingly, they divided all sectors into workplaces requiring manual labor and highly automated settings and found that productivity dropped by as much as 4% per degree when temperatures rose above 27°C in workplaces requiring manual labor, while this effect is not observed in highly automated settings. For workers, they found that a 1°C increase in the ten-day temperature average raised the probability that a worker would be absent by as much as 5%, and absenteeism increased in both labor-intensive and automated manufacturing processes. This decline was large enough to explain the entire reduction in India's economic output in hot years.

3.3 Climate Change and Economic Performances in Manufacturing

Previous studies stress that the negative effects of climate change are widespread, but the magnitudes of the impact on productivity differ across geographical, social, political, and economic factors. Although the determinants of productivity growth such as FDI, exports, and innovation are diverse, their effects vary depending on qualitative factors such as the level of technology, human resources (i.e., education level), institutional quality, and political stability in each country, and climate change is no exception. The direct impacts of climate change occur in the agricultural sector, while in the manufacturing sector, the effects are indirect and occur through various mechanisms. Observations at the economy-wide level of a non-linear, concave and single-peaked relationship between climate change and productivity do not always hold true at the sectoral level (Schleypen et al. 2021). Given that the impact of climate change on agriculture and service varies by situation, it is crucial to understand how the manufacturing sector is linked to these industries (i.e., the importance of industrial structure). Hence, the impact on manufacturing sectors depends on the linkage with agriculture and service, and whether the sector holds a comparative advantage.

Unlike agriculture, manufacturing is highly diverse such as labor, capital, or technology-intensive industries, homogenous or heterogeneous products, and outdoor or indoor workplaces, and the key manufacturing industries vary by country. Also, since much of the work is done indoors in manufacturing, productivity changes are more directly related to the adaptability of businesses, such as the establishment of heating and cooling systems rather than the climate change itself. Government-level adaptation and policy intervention are also important. The examples are policies or regulations of shifting working hours and cool roofs, climate-smart municipal design, and constructing social infrastructures. Regarding adaptive capacity of both company and government levels, the level of technology is crucial.

Consequently, the impact of climate change on productivity in manufacturing can vary depending on each country's industrial structure and capacity to respond. Tol (2009) addressed that the labor productivity impacts of climate change are unknown, noting the wide gap in previous studies. Lai et al. (2023) also addressed that although previous studies has detected various adaptation strategies, the conclusions are mixed. However, most previous studies recognized that the negative effects of climate change on productivity would be minimized by technology, health care, and the small role played by agriculture in developed countries. However, developing economies may experience more negative effects. As most developing countries depend heavily on agriculture and have lower technology level for capacity to respond, the effects of climate change on productive croplands and manufacturing are especially likely to threaten both the welfare of the population and the economic development of these regions. This paper aims to empirically analyze these mechanisms and arguments for manufacturing sectors in APO member economies in the next section.

4. Econometric Specifications and Data Sources

4.1 Econometric Equations and Variables

Based on the theoretical background, I build up the econometric equation as a main regression model as follows:

$$\ln LP_{it}^{m} = \beta_0 + \beta_1 TP_{it} + \beta_2 PC_{it} + \mu_i + \tau_t + \epsilon_{it} \qquad (1)$$

where *m*, *i*, and t refer to manufacturing, countries (21 APO Members), and years (1970–2021), respectively.

As the dependent variable, $\ln LP_{it}^{m}$ is the log of labor productivity in manufacturing of i at t. Among various proxies for productivity, labor productivity is the key link between climate change and economic outcomes (Heal and Park 2013). Acevedo et al. (2020) showed that the negative effects of climate change on economies run through a decline in investment, a depression in labor productivity, a deterioration in human health, and a decrease in agriculture and industrial output. Albert et al. (2021) also showed that climate change affected labor reallocation from agriculture to manufacturing, not capital reallocation. Somanathan et al. (2021) showed that an increase in temperatures raised the probability of absenteeism, irrespective of sectors. Sam Fankhauser et al.

(2018) showed that the effect of heat stress on labor productivity is a key economic impact of climate change, which could affect national output and workers' income.

The two key variables of TP_{it} and PC_{it} are the levels of temperature and precipitation anomalies, respectively, representing departures from reference values or long-term averages. μ_i is a dummy variable for i to control a country's innate time-invariant characteristics that might affect labor productivity, such as geographic location. In this paper, country-specify dummies can capture historical temperature and precipitation effects in each country. τ_t is a dummy for t to control the macroeconomic environment that might affect labor productivity, such as economic recession and global financial crisis. In this paper, year dummies explicitly capture the time path by which contemporaneous temperature and precipitation effects might manifest themselves. ϵ_{it} denotes an error term.

Based on the theoretical background and the UN's country classification, I divide the entire members into three groups of high-income, upper-middle income, and lower-middle income members.[13] General results from the previous studies show that climate changes were more likely to negatively affect low-income countries' economies due to their poorer responding capacity and infrastructures. Accordingly, I expect that β_1 and β_2 are more likely to be negative for the group of low-income members.

Also, as shown in figures 3-1 and 3-2, I divide the entire sample period into three groups: the 1970s and 1980s (1970–89), the 1990s and 2000s (1990–2009), and the 2010s and early 2020s (2010–21). Figures 3-1 shows that the average manufacturing share in GDP in upper-middle income members sharply increased during the 1970s and 1980s, while that in lower-middle income members sharply increased during the 1990s and 2000s. Since the 2010s, the average manufacturing share in GDP in high income members has been a sharp rise. The trend of average labor productivity in manufacturing sector shows a similar pattern in figure 3-2.

In (1), there seems to be no endogeneity issue from reverse causality, because climate changes are clearly exogeneous variables (Barrios et al. 2010, Burke et al. 2015).[14] However, there still seems to be omitted variable bias. Accordingly, I build up the following econometric equation to see how other country factors affect manufacturing productivity and the effect of climate change on manufacturing productivity varies in country characteristics.

$$\ln LP_{it}^{m} = \beta_0 + \beta_1 TP_{it} + \beta_2 PC_{it} + \beta_3 X_{it} + \beta_4 (TP_{it} \times X_{it}) + \beta_5 (PC_{it} \times X_{it}) + \mu_i + \tau_t + \epsilon_{it} \quad (2)$$

where all variables except for X_{it} and its interaction terms are the same as in (1).

X_{it} denotes a vector of country characteristics that might affect labor productivity in manufacturing. Isaksson (2007) addressed four categories for these characteristics: 1) creation, transmission, and absorption of knowledge, 2) factor supply and efficient allocation, 3) institutions, integration, and invariants, and 4) competition, social dimension, and environment. An accumulation of knowledge, research and development, human resources, government expenditure, and openness are also important factors for productivity (Hall and Mairesse 1995, Guellec and Potterie 2004). Based on

13 High-income members are Hong Kong, Japan, Singapore, ROK, and ROC. Upper-middle income members are Fiji, Indonesia, I.R. Iran, Malaysia, Mongolia, Thailand, and Turkiye. Lower-middle economies are Bangladesh, Cambodia, India, Lao PDR, Nepal, Pakistan, Philippines, Sri Lanka, and Vietnam.

14 Some papers indicate that cities might experience an increase in temperature due to growth in area and infrastructure (i.e., heat island effects), as an issue of endogeneity. However, it will not be problem for this paper because it considers the level of temperature anomaly instead of its average.

the previous studies, I consider the log of GDP per capita (ln $GDPC_{it}$), the log of gross fixed capital formation (ln $GFCF_{it}$), the log of trade openness (ln $OPEN_{it}$), the log of capital input in IT sectors (ln $CPIT_{it}$), and the log of labor quality (ln $LABQ_{it}$). I expect that these factors will directly affect labor productivity in manufacturing and, at the same time, the effect of climate change on manufacturing productivity will depend on their levels. For example, considering X_{it} as ln $GDPC_{it}$, if β_1 is negative but β_4 is positive with statistical significance, then it is concluded that temperature anomaly decreases labor productivity, but these negative effects are less prominent in countries with higher GDP per capita or income. Based on literature review, I expect β_4 and β_5 to be positive with statistical significance for all country characteristics: countries with higher income, greater capital investment, greater trade openness, technological superiority, and greater labor quality will be more likely to endure the negative effects of climate changes on productivity in manufacturing.

In the regressions, I consider the two-way fixed-effects model that can alleviate omitted variable bias by eliminating μ_i and considering τ_t. I perform the two F-tests to verify the reliability of the fixed-effects model by testing the null hypotheses that sector dummies or year dummies are all together zero, respectively. If the test results reject the null hypotheses, the two-way fixed-effects model is preferred over the pooled ordinary least squares (OLS).

4.2 Data Collection and Summary Statistics

The database consists of 21 APO members from 1970 to 2021. As a main data source, the APO provides climate information such as annual average temperature and precipitation, as well as various country-level characteristics such as GDP, capital input, and labor input. Based on these, the dependent variable in the regression is defined as the value of final goods divided by total numbers of employees in manufacturing. Thus, LP_{it}^{m} represents output per capita in manufacturing. Among the independent variables, GDP per capita is calculated as GDP divided by total population. Trade openness is calculated as the sum of exports and imports of goods and services relative to GDP. GDPs of both nation- and manufacturing-levels, gross capital formation, exports, and imports are calculated at constant prices of the reference year, 2020. Capital input in IT sectors and labor quality are indexed on the reference year, 2010 (i.e., the year of 2010 = 1.0). Following the methodology developed by the World Meteorological Organization (WMO), the temperature anomaly is defined as the difference between the average yearly temperature and the average temperature over the 1961–90 period as the reference. In the same way, the precipitation anomaly is defined as the difference between the average yearly precipitation and the average precipitation over the 1961–90 period as the reference.

Table 3-3 reports summary statistics for variables in the regression. I check correlation coefficients among independent variables and find no multicollinearity, showing less than the absolute value of 0.8.

TABLE 3-3

DESCRIPTIVE STATISTICS

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
LP^m_{it}	1,092	32,662.69	35,220.59	592.595	328,098.1
TP_{it}	1,113	0.402	0.525	-1.388	2.791
PC_{it}	1,113	25.132	251.317	-865.717	1,567.583
$GDPC_{it}$	1,092	13,708.38	16,915.42	1,139.407	121,655.4
$GFCF_{it}$	1,092	2.07e+11	3.87e+11	3.16e+08	3.11e+12
$OPEN_{it}$	1,092	0.718	0.710	0.005	3.954
$CPIT_{it}$	1,092	0.618	1.000	0	7.9
$LABQ_{it}$	1,092	0.825	0.213	0.216	1.521

5. Empirical Results

5.1 Main Results

Table 3-4 reports the regression results for the entire APO members, high income, upper-middle income, and lower-middle income members. In all regressions, the results from F-tests show that the two-way fixed-effects model is preferred over the pooled OLS. The results in table 3-4 are as follows. In the sample of the entire APO members in column (1), the coefficient estimate of temperature anomaly is negative and statistically significant, implying that the level of temperature anomaly negatively affected labor productivity in manufacturing sector: labor productivity in manufacturing sector decreased by 6.9% when the level of temperature anomaly increased by 1°C. However, the coefficient estimates of precipitation anomaly is statistically insignificant, implying that there was no evidence for the effects of change in precipitation on labor productivity in manufacturing in the entire APO member economies.

When considering only high-income APO members in column (2), the empirical results show that all coefficient estimates are statistically insignificant, implying that both temperature and precipitation anomalies did not affect labor productivity in manufacturing. When considering upper-middle and lower-middle income APO members in columns (3) and (4), all coefficient estimates of temperature anomaly are negative and statistically significant, implying that the level of temperature anomaly negatively affected labor productivity in the manufacturing sectors of these members: a 1°C increase in temperature anomaly reduced manufacturing productivity in upper-middle and lower-middle income members by 8.9% and 20.9%, respectively. The coefficient estimate of precipitation anomaly in lower-middle income members is statistically insignificant in column (4), while that in upper-middle income members is statistically significant but its value is too low to be meaningful. Thus, these results imply that there was no evidence for the effects of change in precipitation on labor productivity in manufacturing in upper-middle and lower-middle income member economies.

Consequently, the regression results from table 3-4 show that the negative effects of temperature anomaly on manufacturing productivity are widespread in APO member economies, but the magnitudes of the impact differ across a government's income level. Especially, temperature anomaly had substantial negative effects on manufacturing productivity in poor countries, but little effects in rich ones. These negative effects are greatest in lower-middle income members. These results are very consistent with previous studies that show the adverse effects of temperature change on a developing country's economy due to its insufficient adaptable capacity to climate change. Meanwhile, a developed country has solid infrastructures and systems, and its ability to adapt to climate change mitigates these negative effects in the case of APO member economies.

TABLE 3-4

EMPIRICAL RESULTS: HIGH INCOME VS. UPPER-MIDDLE INCOME VS. LOWER-MIDDLE INCOME MEMBERS

	Entire Members	High Income Members	Upper-middle Income Members	Lower-middle Income Members
	(1)	(2)	(3)	(4)
TP_{it} (Temperature Anomaly)	**-0.069*** **(0.039)**	0.013 (0.077)	**-0.089**** **(0.043)**	**-0.209**** **(0.095)**
PC_{it} (Precipitation Anomaly)	0.000 (0.000)	-0.000 (0.000)	**0.000*** **(0.000)**	-0.000 (0.000)
Overall R_2	0.208	0.617	0.440	0.230
F-test ($\mu_i = 0$)	206.74***	197.71***	55.56***	79.84***
F-test ($\tau_t = 0$)	16.07***	14.61***	6.71***	4.31***
Observations	1,092	260	364	468

Notes: 1. *, **, *** denote significance at 1%, 5%, 10% levels, respectively.
2. Figures in parentheses are standard errors. 3. Year dummies are included in all regressions.

Table 3-5 reports the regression results for three periods: the 1970s and 1980s, the 1990s and 2000s, and the 2010s and early 2020s. In all regressions, the results from F-tests show that the two-way fixed-effects model are preferred over the pooled OLS. The results in table 3-5 are as follows. In the sample of the 1970's and 1980's in column (1), all coefficient estimates are statistically insignificant, implying that the level of temperature and precipitation anomalies did not affect labor productivity in the manufacturing sectors of APO member economies. However, temperature anomaly has negatively affected manufacturing productivity in APO member economics since the 1990s, showing that its coefficient estimates in columns (2) and (3) are negative and statistically significant. Labor productivity in manufacturing sector decreased by 9.8% in the 1990s and 2000s, and 6.2% in the 2010s and early 2020s when the level of temperature anomaly increased by 1°C. Meanwhile, all coefficient estimates of precipitation anomaly in columns (2) and (3) are still statistically insignificant, implying that there was no evidence for the effects of change in precipitation on manufacturing productivity in APO member economies, regardless of the period.

Consequently, the regression results from table 3-5 show that the negative effects of temperature anomaly on manufacturing productivity are widespread in APO member economies, but the magnitudes of the impact differ across periods. Temperature anomaly has had substantial negative effects on manufacturing productivity in APO member economies since the 1990s, but had little effects during the 1970s and 1980s. These negative effects were especially greatest during the 1990s and 2000s, when the average manufacturing share of lower-middle income members started sharply increasing. It seems that these lower-middle income members have insufficient adaptable capacity to climate change. Meanwhile, the negative effects of temperature anomaly still continued during the 2010s and early 2020s, but its absolute magnitude decreased from 9.8% to 6.2%. During this period, both average manufacturing share and productivity in high income members sharply rose. It seems that these high-income members have robust infrastructures and systems, and their ability to adapt to climate change mitigates these negative effects in the case of APO member economies.

TABLE 3-5

EMPIRICAL RESULTS: THE 1970S AND 1980S VS. THE 1990S AND 2000S VS. THE 2010S AND EARLY 2020S

	1970s & 1980s	1990s & 2000s	2010s & early 2020s
	(1)	(2)	(3)
TP_{it} (Temperature Anomaly)	-0.036 (0.038)	**-0.098**** **(0.038)**	**-0.062**** **(0.025)**
PC_{it} (Precipitation Anomaly)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Overall R_2	0.032	0.031	0.003
F-test ($\mu_i = 0$)	385.85***	284.72***	575.98***
F-test ($\tau_t = 0$)	13.09***	14.59***	19.39***
Observations	420	420	252

Notes: 1. *, **, *** denote significance at 1%, 5%, 10% levels, respectively.
2. Figures in parentheses are standard errors. 3. Year dummies are included in all regressions.

5.2 Interaction Terms with Country Characteristics

Table 3-6 reports the regression results for adding country characteristics and their interaction terms with temperature and precipitation anomalies, respectively. In all regressions, the results from F-tests show that the fixed-effects model are preferred over the pooled OLS, but year dummies are unnecessary. Hence, I report the results from the fixed-effects model,[15] but supplementarily explain some results from the two-way fixed-effects model. The results in table 3-6 are as follows. The coefficient estimate of temperature anomaly is negative and statistically significant in column (2), but statistically insignificant in columns (3), (4), and (5). In the results from the two-way fixed-effects model, these coefficient estimates become statistically significant with a negative sign. Conjecturing that a multicollinearity problem between temperature anomaly and its interaction terms with country characteristics might cause the change in statistical significance and the positive sign in column (1), the results generally imply that the level of temperature anomaly negatively affected labor productivity in manufacturing sector of APO member economies. Thus, the results of temperature anomaly in table 3-6 are consistent with those in table 3-4 in general. In all columns, the coefficient estimates of precipitation anomaly are still statistically insignificant, ensuring that there was no evidence for the effects of change in precipitation on manufacturing productivity in APO member economies.

In all columns, the coefficient estimates of ln $GDPC_{it}$ are positive and statistically significant, implying that the increase in GDP per capita led to the increase in manufacturing productivity, as expected: labor productivity in manufacturing sector increased by about 0.9% when the national income level increased by 1% in the case of APO member economies. In all columns, the coefficient estimates of ln $GFCF_{it}$ are negative and statistically significant, implying that the increase in a nation's gross fixed capital formation led to the decrease in manufacturing productivity. It seems that as a production factor, capital formation at the national level substituted for labor force in manufacturing sectors in the case of APO member economies. In all columns, the coefficient

15 The regression results of the two-way fixed-effects model are little different from those of the fixed-fixed effects model.

estimates of ln $OPEN_{it}$ are negative and statistically significant, implying that the increase in trade openness led to the decrease in manufacturing productivity. It seems that APO members mostly consist of low-income countries, and their comparative advantages are in agriculture sectors. Based on neoclassical trade theories (e.g., the Heckscher-Ohlin model), it seems that trade openness might mostly lead to an increase in agricultural output, redistributing production factors from manufacturing, in the case of APO member economies.

In all columns, the coefficient estimates of ln $CPIT_{it}$ are positive and statistically significant, implying that the increase in capital input in IT led to the increase in manufacturing productivity. It seems that capital investments to IT sectors in manufacturing improved labor productivity, although its national level in all sectors substituted for labor force in the case of APO member economies. In all columns, the coefficient estimates of ln $LABQ_{it}$ are negative and statistically significant, implying that the increase in labor quality led to the decrease in manufacturing productivity. As the labor quality index is estimated by workers' average education level and in general, workers in service sectors are requested to have a higher education level, it seems that the increase in labor quality might benefit service sectors at the expense of manufacturing sectors in the case of APO member economies.

As a key variable in table 3-6, the coefficient estimates of $TP_{it} \times \ln GDPC_{it}$, $TP_{it} \times \ln GFCF_{it}$, and $TP_{it} \times \ln LABQ_{it}$ are positive and statistically significant in columns (1), (2), and (5), respectively. These results imply that the negative effects of temperature anomaly were less prominent when a government has greater national income, greater aggregate capital formation, and higher labor quality in the case of APO member economies. These results are congruent with those from previous studies, addressing that high-income countries have greater ability to adapt to climate change, as they have solid infrastructures and systems through greater investments in facilities, equipment, education, and vocational training programs. Meanwhile, the coefficient estimates of $TP_{it} \times \ln OPEN_{it}$ and $PC_{it} \times \ln CPIT_{it}$ are statistically insignificant, implying that trade openness and capital input in IT sectors were not related to a country's ability to adapt to temperature change in the case of APO member economies. For precipitation anomaly, all interaction terms are statistically insignificant, implying that a government's characteristics were not related with its ability to adaption to precipitation change in the case of APO member economies.

TABLE 3-6

EMPIRICAL RESULTS: INTERACTION TERMS WITH COUNTRY CHARACTERISTICS

	(1)	(2)	(3)	(4)	(5)
TP_{it} (Temperature Anomaly)	**0.531*** (0.092)**	**-0.375*** (0.043)**	-0.047 (0.031)	-0.038 (0.029)	-0.020 (0.027)
PC_{it} (Precipitation Anomaly)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
ln $GDPC_{it}$ (GDP per capita)	**0.868*** (0.064)**	**0.954*** (0.059)**	**1.041*** (0.062)**	**1.032*** (0.061)**	**1.019*** (0.061)**
ln $GFCF_{it}$ (Gross Fixed Capital Formation)	**-0.088** (0.037)**	**-0.151*** (0.035)**	**-0.157*** (0.037)**	**-0.152*** (0.036)**	**-0.148*** (0.036)**
ln $OPEN_{it}$ (Trade Openness)	**-0.077*** (0.025)**	**-0.044* (0.025)**	**-0.077*** (0.026)**	**-0.079*** (0.026)**	**-0.081*** (0.026)**
ln $CPIT_{it}$ (Capital Input in IT Sectors)	**0.159*** (0.016)**	**0.158*** (0.016)**	**0.156*** (0.017)**	**0.157*** (0.017)**	**0.157*** (0.017)**
ln $LABQ_{it}$ (Labor Quality)	**-0.839*** (0.071)**	**-0.854*** (0.070)**	**-0.844*** (0.073)**	**-0.850*** (0.073)**	**-0.868*** (0.074)**
$TP_{it} \times$ ln $GDPC_{it}$	**0.124*** (0.019)**				
$PC_{it} \times$ ln $GDPC_{it}$	0.000 (0.000)				
$TP_{it} \times$ ln $GFCF_{it}$		**0.083*** (0.009)**			
$PC_{it} \times$ ln $GFCF_{it}$		0.000 (0.000)			
$TP_{it} \times$ ln $OPEN_{it}$			-0.005 (0.024)		
$PC_{it} \times$ ln $OPEN_{it}$			0.000 (0.000)		
$TP_{it} \times$ ln $CPIT_{it}$				0.002 (0.010)	
$PC_{it} \times$ ln $CPIT_{it}$				0.000 (0.000)	
$TP_{it} \times$ ln $LABQ_{it}$					**0.144** (0.070)**
$PC_{it} \times$ ln $LABQ_{it}$					0.000 (0.000)
Overall R_2	0.756	0.733	0.715	0.719	0.723
F-test ($\mu_i = 0$)	80.35***	86.84***	77.32***	76.55***	76.57***
F-test ($\tau_t = 0$)	0.33	0.39	0.44	0.52	0.36
Observations	1,091	1,091	1,091	1,091	1,091

Notes: 1. *, **, *** denote significance at 1%, 5%, 10% levels, respectively.
2. Figures in parentheses are standard errors.
3. Year dummies are included in all regressions.

6. Conclusion and Policy Implication

6.1 Summary

Recent trends in climate change show a rapid increase in global temperatures, more frequent severe weather events, accelerated melting of polar ice caps, and rising sea levels. These changes are primarily driven by human activities such as fossil fuel consumption and deforestation. The resulting disruptions to ecosystems and biodiversity underscore the urgent need for global cooperation and comprehensive action to address and adapt to these evolving challenges. While all regions experience some level of climate change, the degree and type of impact can differ across continents and countries. For instance, some areas might face severe droughts and wildfires, while others could experience increased flooding and storms. This variability necessitates tailored approaches to mitigation and adaptation strategies that consider the specific challenges and needs of each region.

The direct impact of climate change on economy is most evident in the agricultural sector, where changes in temperature, precipitation, and extreme weather events can significantly affect crop yields and livestock. By contrast, the manufacturing sector experiences more indirect effects. Unlike agriculture, manufacturing is highly diverse and the key manufacturing industries vary by country. Hence, the effects of climate change on manufacturing are often mediated through various mechanisms. For instance, the ability to establish efficient heating and cooling systems can play a critical role in maintaining productivity, highlighting the importance of technological adaptation in mitigating climate change impacts in this sector. Also, the relationship with agriculture, comparative advantage, and diversity are notable factors, with each country having different leading manufacturing industries.

Accordingly, this chapter empirically examines how climate change affected the manufacturing productivity of APO member economies during the 1970–2021 period, focusing on different environmental factors across them and provides policy implications for strategies for adaptation and mitigation. The regression results are as follows. First, in general, temperature anomalies negatively affected manufacturing productivity, especially in lower-middle-income APO members, with a 1°C increase leading to significant productivity declines (6.9% for all members, 8.9% for upper-middle, and 20.9% for lower-middle income members). However, high-income members showed no significant impact from temperature or precipitation anomalies. Also, precipitation anomalies generally showed no significant effect across all income levels. An increase in precipitation could have positive effects, such as increasing electricity supply through hydropower generation and also, in the case of manufacturing, which mostly involves indoor work, changes in precipitation are expected to have little impact.

For period analyses, the results show that temperature and precipitation anomalies did not affect productivity during the 1970s and 1980s. From the 1990s onwards, however, temperature anomalies have had significant negative effects on productivity, with a 9.8% decrease in the 1990s and 2000s and 6.2% in the 2010s and early 2020s per 1°C increase. During the 1990s and 2000s, the average manufacturing share of lower-middle income members started sharply increasing, and it seems that they have insufficient adaptable capacity to climate change. During the 2010s and early 2020s, both average manufacturing share and productivity in high income members sharply rose. It seems that they have robust infrastructures and systems, and their ability to adapt to climate change mitigates these negative effects. Accordingly, the absolute magnitude of the negative effects decreased from 9.8% to 6.2%. Precipitation anomalies still remained statistically insignificant throughout these periods.

The previous studies showed that the effects of temperature change on manufacturing productivity vary depending on a country's qualitative factors such as the level of technology, human resources (or education level), institutional quality, and political stability in each country. In this respect, this chapter considers the interaction terms of climate change with various country characteristics in the regressions. The regression results show that temperature anomalies negatively impacted productivity, but their effects were less severe in countries with higher GDP per capita, greater capital formation, and higher labor quality. The results from the interaction terms imply better adaptation to temperature changes in wealthier countries with better infrastructure and systems. However, no significant adaptation capacity was found concerning precipitation changes in the interaction terms.

Consequently, the empirical results in the case of APO member economies consistently indicate that temperature anomalies negatively affect manufacturing productivity, particularly in lower-income countries, due to insufficient adaptation capacity. Higher-income APO member economies mitigate these effects through better infrastructure and systems. Precipitation anomalies, however, do not show a significant impact on productivity across APO member economies.

6.2 Policy Implication

The main findings of this chapter through meticulous literature review and regression analyses imply that the effects of temperature change on manufacturing productivity in APO member economies vary depending on a member's qualitative factors, such as the level of technology, human resources, institutional quality, and political stability. In other words, the economic impact of temperature change can vary depending on each member's industrial structure and capacity to respond. In particular, developing economies may experience more negative effects and, in the case of manufacturing, since much of the work is done indoors, productivity changes are more directly related to the adaptability of businesses rather than to climate change itself. Regarding adaptive capacity, the level of technology, various regulations, and social infrastructure are crucial.

Accordingly, adaptation policies for international climate change in manufacturing productivity should focus more on improving infrastructure and facilities such as heating and cooling systems and indoor workplaces as well as technology levels. Also, it is important to improve workers' quality with education and job training programs in manufacturing. These policies should be focused on developing countries. Table A1 and Figure A3 in the appendix show the level of average electric power consumption (kWh per capita) for high, upper-middle, and lower-middle income groups in APO member economies. Considering that the typical example of adaptability is the establishment of heating and cooling systems, Figure A3 implies that the gap in the ability to respond to climate change among APO member economies appears to be very large: the average electric power consumption per capita is about 574 kWh for the lower-middle-income group, 2,607 kWh for the upper-middle-income group, and 8,311 kWh for the high-income group. This is consistent with the empirical results, which showed that there was no effect of decreased manufacturing productivity from a 1°C change in high-income countries, but it was present only in upper-middle- and low-middle-income economies. The gap between upper-middle- and low-middle-income economies is also very large. This fact provides the basis for the need for close cooperation between the related APO's adaption strategy and ODA projects, along with the establishment of a long-term vision for responding to climate change.

Mitigation policies for international climate change in manufacturing productivity should focus more on changing the use of production facilities from traditional methods to eco-friendly green systems such as solar light power generators, especially in developed countries with capacity for high income and technology levels. It is also important to support certification systems and infrastructures to tighten environmental regulations in manufacturing production, especially in developing countries. Table A2 and Figure A4 in the appendix show the cumulative number of WTO TBT (Technical Barriers to Trade) notifications for environmental protection purposes for APO member economies. Among APO member economies, the high-income group has the most environmental regulations with a total of 293 cases, followed by the low-middle-income group with 249 cases, and the upper-middle-income group with 142 cases. It can be seen that among developing countries, the upper-middle-income economies have the least number of environmental regulations. However, if India, which ranks first with 161 cases, is excluded from the group of lower-middle-income economies, it can be seen that most members, excluding high-income countries, are relatively passive in enacting environmental regulations. Especially in the case of developing countries, it is pointed out that even if environmental regulations are established, the absence of administrative bodies, certification infrastructures, and systems to implement them is a problem (Choi and Jang 2018). This fact provides the basis for the need for APO's mitigation strategies to be also carried out in conjunction with ODA projects, in addition to adaptation strategies for climate change.

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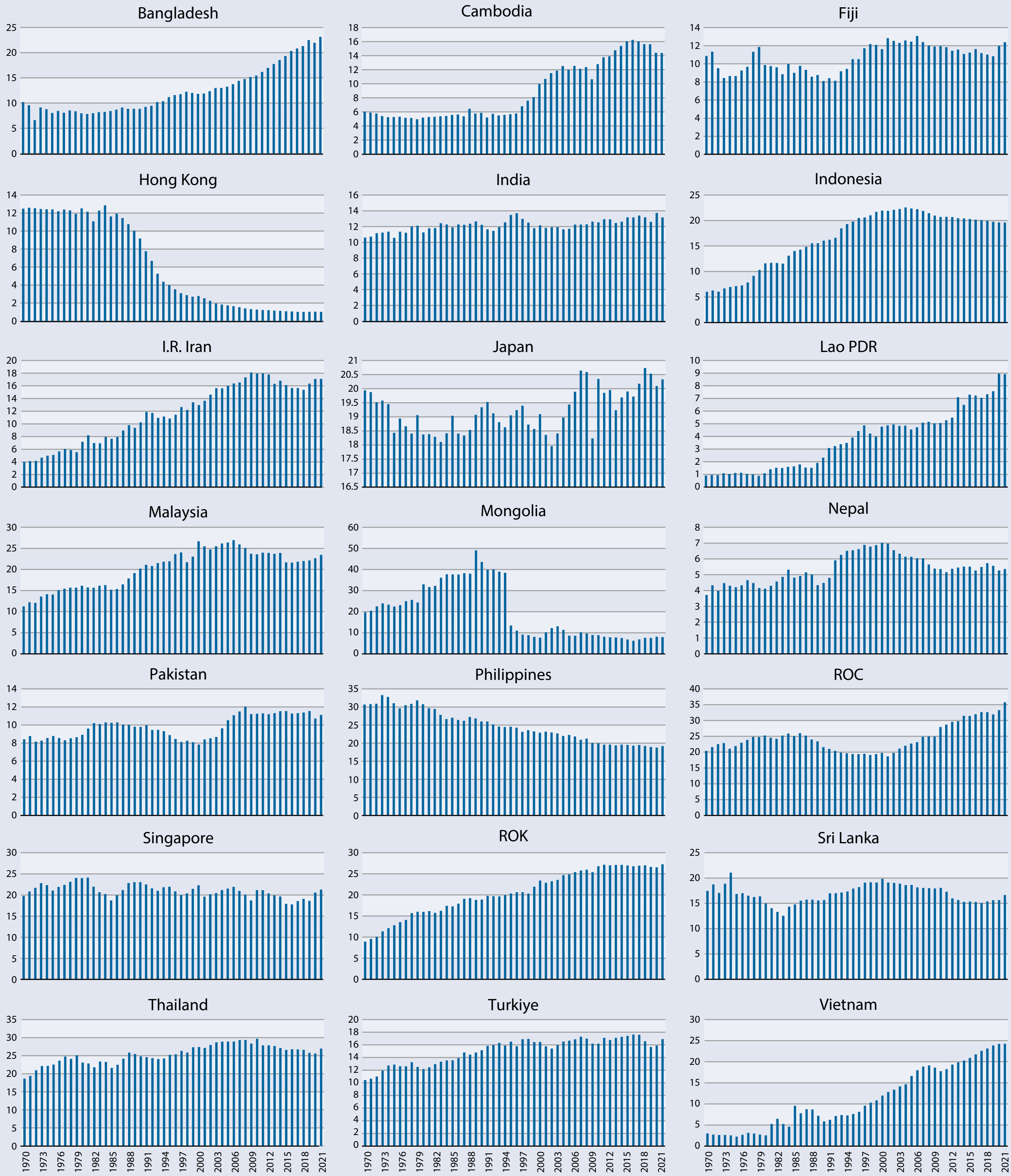
Appendix

FIGURE A1

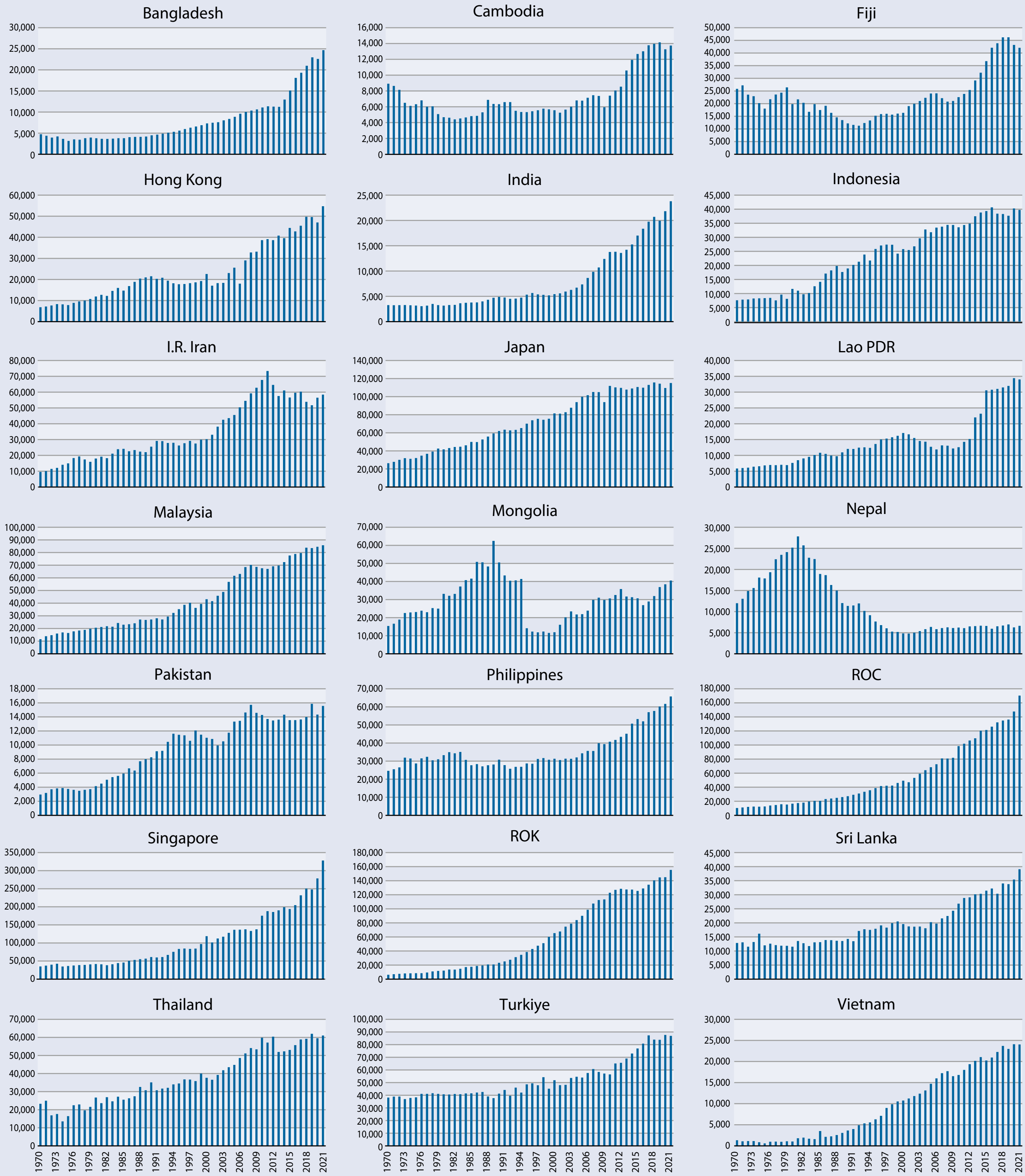
EACH MEMBER'S TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)



Source: Author's calculations based on the APO Productivity Database

FIGURE A2

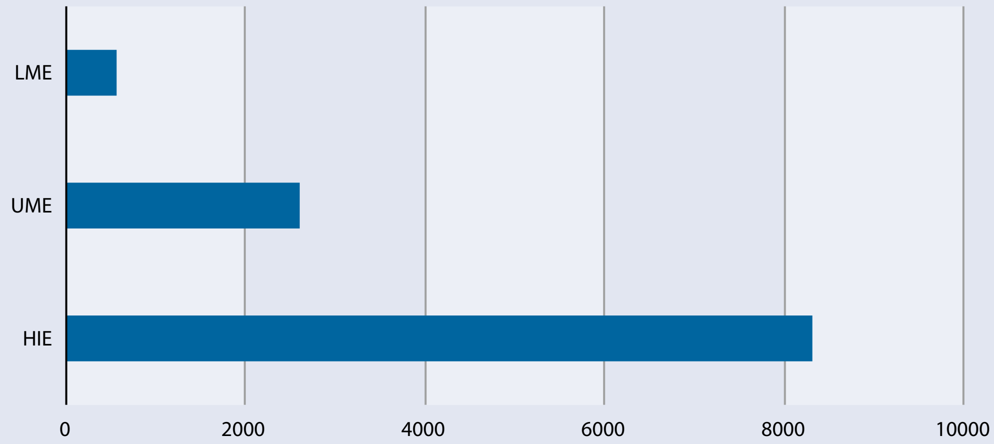
EACH MEMBER'S TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



Source: Author's calculations based on the APO Productivity Database

FIGURE A3

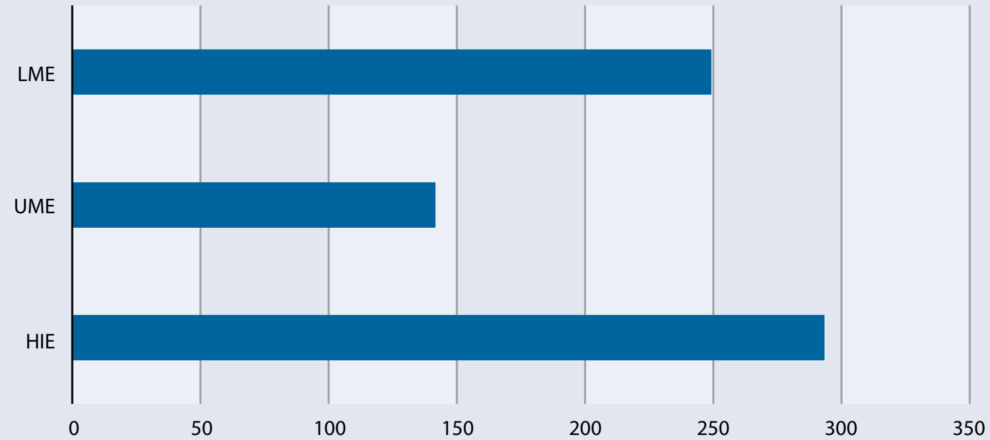
AVERAGE ELECTRIC POWER CONSUMPTION (KWH PER CAPITA, 2014) FOR INCOME GROUPS OF APO MEMBER ECONOMIES



Note: 1. Fiji, Lao PDR, ROC are excluded as being omitted in the database.
Source: Author's calculations based on the World Bank World Development Indicator (WDI) Database

FIGURE A4

CUMULATIVE NUMBER OF ENVIRONMENTAL REGULATIONS FOR INCOME GROUPS OF APO MEMBER ECONOMIES



Note: 1. The number of technical regulations for environmental protection purposes is compiled from WTO TBT notifications
2. I.R. Iran is excluded as a non-member country of WTO.
Source: Author's calculations based on the WTO e-Ping SPS & TBT Platform

TABLE A1

AVERAGE ELECTRIC POWER CONSUMPTION FOR APO MEMBER ECONOMIES (KWH PER CAPITA, 2014)

Member	kWh	Member	kWh
ROK	10,496.51	Vietnam	1,431.16
Singapore	8,844.69	Indonesia	808.42
Japan	7,819.72	India	797.35
Hong Kong	7,083.27	Philippines	690.77
Malaysia	4,539.50	Sri Lanka	519.55
I.R. Iran	2,927.79	Pakistan	419.68
Turkiye	2,848.97	Bangladesh	317.25
Thailand	2,483.56	Cambodia	272.50
Mongolia	2,032.16	Nepal	143.52

Note: Fiji, Lao PDR, ROC are excluded as being omitted in the database.
Source: Author's calculations based on the World Bank World Development Indicator (WDI) Database

TABLE A2

CUMULATIVE NUMBER OF ENVIRONMENTAL REGULATIONS FOR APO MEMBER ECONOMIES, 1995–2024.10.

Member	Cases	Member	Cases
India	161	Hong Kong	16
ROC	105	Indonesia	10
Thailand	74	Philippines	10
Japan	69	Mongolia	7
Republic of Korea	60	Malaysia	4
Turkiye	47	Nepal	2
Singapore	43	Sri Lanka	2
Vietnam	44	Bangladesh	1
Pakistan	21	Fiji	0
Cambodia	19	Lao PDR	0

Note: 1. The number of technical regulations for environmental protection purposes is compiled from WTO TBT notifications
2. I.R. Iran is excluded as a non-member country of WTO.
Source: Author's calculations based on the WTO e-Ping SPS & TBT Platform

CLIMATE CHANGE ON SERVICE PRODUCTIVITY AND POLICY IMPLICATIONS

1. Introduction

The impact of climate change on economic growth has been a topic of considerable research since the late 20th century. Traditionally, studies have primarily focused on how changes in temperature and precipitation affect agricultural productivity, with an increasing body of work examining the effects on manufacturing sectors. However, there remains a notable gap in research regarding the influence of climate change on service industry productivity, despite this sector's growing prominence in the global economy.

As economies evolve and industrial structures become more sophisticated, the service sector's share of overall economic activity continues to expand. This shift necessitates a deeper understanding of service sector productivity dynamics, particularly in the context of climate change. The rising importance of services means that their vulnerability to climate change could have significant implications for economic stability and growth.

Climate change can profoundly impact service industries such as tourism, transportation, and hospitality, all of which are highly sensitive to climatic fluctuations. Even subtle shifts in climate patterns, such as changes in temperature, precipitation, or extreme weather events, can disrupt tourism flows, alter the seasonality of destinations, and potentially reduce visitor numbers and shorten peak travel seasons. The hospitality industry, including restaurants and hotels, faces similar risks, as rising temperatures may reduce the attractiveness of popular tourist locations, leading to lower occupancy rates and fewer customers. Likewise, the transportation industry is vulnerable to extreme weather events that can disrupt infrastructure, delay services, and increase operational costs, impacting both tourism and supply chains.

This chapter aims to explore the impacts of climate change on service sector productivity in Asian countries, with a focus on APO members. Given the significant role of service-focused economies in Southeast Asia, such as the tourism sectors in Thailand, the Philippines, and Indonesia, understanding these impacts is crucial. By investigating these effects, the study seeks to provide insights that can inform policy and support the development of resilient service sectors capable of adapting to the challenges posed by climate change.

The data used in this chapter is unique, as it includes climate information such as temperature and precipitation over a finely divided geographical grid spanning 40 years. We follow the model framework proposed by Burke et al. (2015), incorporating quadratic terms for temperature and precipitation to capture the nonlinear effects of climate change on economic growth.

Our estimation results show that changes in temperature have a negative effect on labor productivity in the service sector. Moreover, the results by sub-service sectors indicate that the impact of temperature change varies across different industries. For example, sectors such as hotels and restaurants may be more affected, as temperature changes can significantly impact the tourism industry, while other sectors, such as finance, are rarely affected by temperature fluctuations.

The negative effect on service sector productivity implies that efforts to reduce climate change are critical for maintaining productivity levels in this sector. For instance, transitioning to renewable energy and promoting energy efficiency can help mitigate rising temperatures, allowing the service sector to achieve its full economic growth potential. Furthermore, our findings highlight the need for tailored adaptation strategies for each service industry in response to temperature changes. These could include investing in climate-resilient infrastructure in vulnerable sectors like tourism and strengthening supply chains to mitigate climate-related disruptions. Additionally, developing climate insurance products can help reduce the financial risks faced by businesses impacted by temperature changes.

The remaining chapters are organized as follows: Chapter 2 reviews the related literature on service productivity and climate change, providing the background for this study. Chapters 3 and 4 estimate the effects of climate change on the overall service sector and its sub-industries, presenting the results. Finally, the study concludes with policy implications and recommendations.

2. Background and Conceptual Review

1) The Evolving Role of Services in Economic Growth

The perception of the service sector's contribution to economic growth has undergone significant transformation in recent decades. Initially overlooked when manufacturing and agriculture were the primary economic drivers, services are now recognized as a crucial component of modern economies. This shift in perspective has been driven by the sector's growing share in GDP and employment across many countries, particularly in developed economies.

Early economic theories, such as those proposed by Baumol and Bowen (1965), raised concerns about the service sector's potential to hinder economic growth due to perceived lower productivity. However, as economies have matured and the nature of services has evolved, these views have been challenged. Contemporary research, including work by Maroto and Rubalcaba (2008) and Lee and McKibbin (2018), has highlighted the significant and often underappreciated role of services in driving economic growth and innovation.

2) Financial Services and Economic Development

Within the broader service sector, financial services have emerged as a particularly influential subsector. The relationship between financial development and economic growth has been the subject of extensive research, revealing complex and sometimes contradictory effects. Recent studies have explored how financial services can impact economic performance through various channels.

For instance, research by Fonseca and Van Doornik (2022) suggests that improved access to financial services can enhance labor market efficiency, thereby benefiting firms and overall economic productivity. However, the impact of financial development is not uniformly positive across all economic contexts. Naceur et al. (2019) present a nuanced view, arguing that while financial growth can boost economic performance in developing economies, excessive financial sector expansion might have detrimental effects in more advanced economies.

This complexity is further underscored by Ibrahim and Alagidede (2018), who emphasize the importance of balanced growth between the financial sector and the real economy. Their work suggests that the positive impact of financial development on productivity is contingent on maintaining this balance, highlighting the need for carefully calibrated economic policies.

3) Business Services as Drivers of Innovation and Growth

Business services represent another critical component of the service sector that has gained increasing attention from researchers and policymakers. These services, which include consulting, IT, and professional services, play a unique role in fostering innovation and productivity across the broader economy.

Kox and Rubalcaba (2007) have made significant contributions to our understanding of how business services impact economic growth. Their research indicates that these services contribute not only through direct channels such as employment and value creation, but also through indirect effects on knowledge dissemination and innovation. This dual impact makes business services particularly important for long-term economic development.

Building on this work, more recent studies have further illuminated the role of business services in driving economic growth. For example, Shin (2024) has demonstrated how these services contribute to both production processes and innovation activities, creating a virtuous cycle of economic advancement. These findings underscore the importance of fostering a robust business services sector as part of a comprehensive economic development strategy.

4) Climate Change and Its Economic Implications

As our understanding of the service sector's economic importance has grown, so too has awareness of the potential impacts of climate change on economic systems. Climate change presents a complex set of challenges for economies worldwide, with implications that extend across all sectors, including services.

Pioneering work by researchers such as Nordhaus (2006) has revealed non-linear relationships between temperature changes and economic output. Using innovative methodologies and data sets, these studies have shown that while moderate temperature increases may initially benefit some economic activities, more extreme changes are likely to have negative impacts across most sectors.

Subsequent research, including work by Du et al. (2017) and Alagidede et al. (2014), has further refined our understanding of these relationships, revealing regional variations and differences in short-term versus long-term impacts. These studies have highlighted the need for nuanced, context-specific approaches to understanding and addressing the economic impacts of climate change.

5) The Research Gap: Climate Change and Service Sector Productivity

Despite the growing body of literature on both the service sector's economic role and the broader economic impacts of climate change, there remains a significant gap in our understanding of how climate change specifically affects service sector productivity. This gap is particularly notable given the increasing importance of services in many economies, especially in rapidly developing regions like Asia.

Previous studies, such as that by Dell et al. (2012), have noted the challenges in quantifying climate change impacts on the service sector, often due to methodological limitations or data constraints.

This has left a crucial area of economic vulnerability understudied, despite its potential significance for future economic growth and stability.

Our study aims to address this research gap by focusing specifically on the impacts of climate change on service sector productivity in APO members. By leveraging unique climate data and applying advanced econometric techniques, we seek to provide a more nuanced understanding of how temperature and precipitation changes affect different service subsectors.

This research not only contributes to the academic literature but also aims to provide practical insights to policymakers and business leaders. Understanding the specific vulnerabilities of different service industries to climate change can inform the development of targeted adaptation and mitigation strategies, helping to ensure the resilience and continued growth of this vital sector in the face of environmental challenges.

3. Service Sector Trends: Economic and Climate Factors

1) Data

This study utilizes a comprehensive dataset spanning from 1970 to 2019, encompassing both macroeconomic variables and climate indicators. The dataset's end point was chosen to exclude the potential distortions caused by the COVID-19 pandemic, ensuring a focus on long-term trend rather than short-term disruption.

The primary macroeconomic variable of interest is labor productivity in the service sector and its various subsectors. This data is sourced from the APO database, which provides consistently measured and comparable data across APO members.

To calculate labor productivity, we first consider the Gross Domestic Product (GDP) for each sector, measured at 2020 market prices. This figure is adjusted to remove the effects of inflation by using constant prices, ensuring comparability across years. To account for differences in price levels across countries, the GDP figures are further adjusted using 2017 Purchasing Power Parities. The final labor productivity is derived by dividing the GDP by the number of employees in each sector. This method provides a measure of output per worker, offering insights into the efficiency and effectiveness of labor in the service sector.

The climate data used in this study is drawn from Version 4 of the CRUTS (Climatic Research Unit Time Series) dataset, provided by the Climatic Research Unit at the University of East Anglia in the United Kingdom. This dataset is widely recognized in the climate research community for its high quality and comprehensive coverage.

The CRUTS dataset offers high-resolution gridded multivariate climate data, providing a fine-grained view of climate conditions across different regions. Its long-term coverage spans several decades, allowing for the analysis of long-term climate trends and their potential impacts on economic factors. While our study focuses primarily on temperature and precipitation, the dataset includes a range of climate variables, offering potential for future expansion of our analysis. The data is available in monthly time steps, enabling the examination of seasonal patterns and their potential economic impacts. Furthermore, the dataset undergoes rigorous quality control procedures, ensuring the reliability of the climate data used in our analysis.

By combining these macroeconomic and climate datasets, we create a unique panel dataset that allows for the examination of the relationship between climate factors and service sector productivity across different countries and over time. This rich dataset enables us to control for country-specific factors and global trends while focusing on the specific impacts of climate variables on service sector productivity. The use of this comprehensive and high-quality dataset strengthens the robustness of our analysis and provides a solid foundation for drawing meaningful conclusions about the relationship between climate change and service sector productivity in APO members.

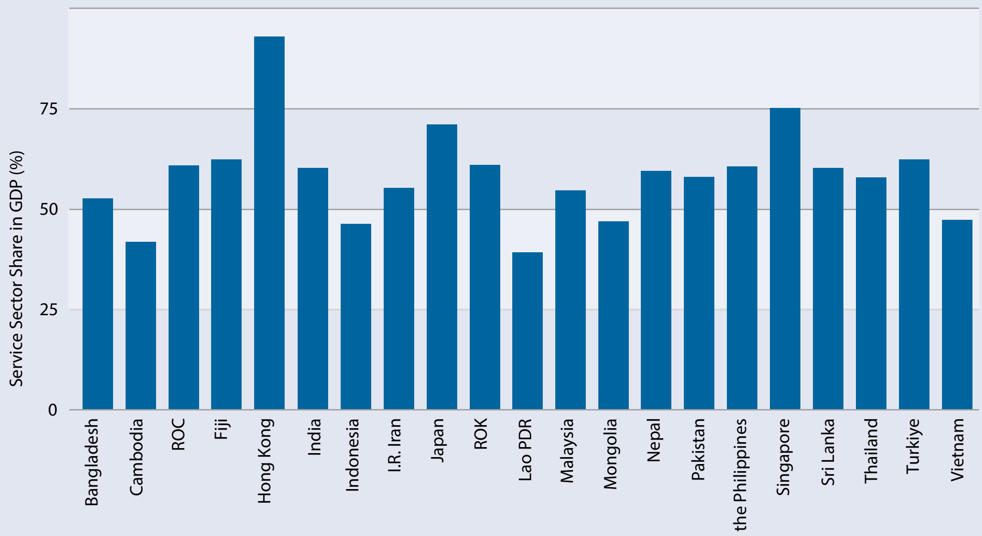
2) Service sector trends

The service sector has become increasingly prominent in the economies of APO members over the past few decades. Figure 3.1 illustrates that as of 2019, services contributed more than half of the total GDP for most of these regions, reflecting a global shift towards service-oriented economies. This trend is particularly pronounced in developed economies such as Hong Kong (92.9%), Singapore (88.5%), and Japan (85.0%), where the service sector accounts for a significant portion of economic output. These high shares indicate the sector's dominance in advanced, post-industrial economies with strong financial and business service sectors.

However, the importance of the service sector varies considerably across the region. Figure 4-1 also shows that countries like Malaysia (66.5%), Thailand (61.2%), and India (57.5%) occupy a middle ground, indicating economies in transition with a balanced mix of services, manufacturing, and agriculture. At the lower end, countries such as Cambodia (41.8%) and Lao PDR (39.8%) demonstrate economies still heavily reliant on agriculture and manufacturing, with services playing a smaller, albeit growing, role.

FIGURE 4-1

SERVICE SECTOR SHARE IN GDP OF 2019



Despite these variations, long-term trends from 1970 to 2020, as depicted in Figure 4-2, reveal a steady increase in the service sector's contribution to the GDP across APO members. This figure shows a general upward trend across most countries, indicating a global shift towards service-based economies. Notably, nations such as India, Bangladesh, and Vietnam have seen a significant upward trajectory in the service sector's GDP share, particularly since the 1990s. This rapid growth coincides with periods of economic liberalization and increased global integration, highlighting these countries' swift economic development and shift towards services-based economies.

When we closely look into the composition of the service sector, Figure 4-3 shows distinct patterns across different sub-sectors. In developed economies like Hong Kong, Singapore, and Japan, financial intermediation, real estate, and business activities (Service 3) play a dominant role, particularly in Hong Kong and Singapore, reflecting their strong positions as global financial hubs. Wholesale and retail trade, hotels, and restaurants (Service 1) also contribute significantly across most economies, especially in countries with strong tourism sectors. Transport, storage, and communications (Service 2) show relatively consistent shares across countries, reflecting the universal importance of these services in all economies.

Interestingly, when we examine the share of sub-service sectors in employment, as shown in Figure 4-4, a different picture emerges. Wholesale and retail trade, hotels, and restaurants (Service 1) tend to be the largest employers in the service sector across most countries. In contrast, financial services, despite their high GDP contribution, employ relatively few people, highlighting the sector's high productivity. This suggests that while the financial industry may not directly drive economic development through job creation, it can indirectly stimulate other industries by channeling necessary funding and contributing significantly to GDP.

FIGURE 4-2

SHARES OF WHOLESALE SERVICE SECTOR IN GDP

FIGURE 4-3

SHARES OF SERVICE SUB-SECTORS IN GDP

Note: Each service sector consists, respectively, of "wholesale and retail trade, repair of vehicles and household goods, and hotels and restaurants," "transport, storage, and communications," "financial intermediation, real estate, renting, and business activities," and "community, social, and personal services," in the order of numbering.

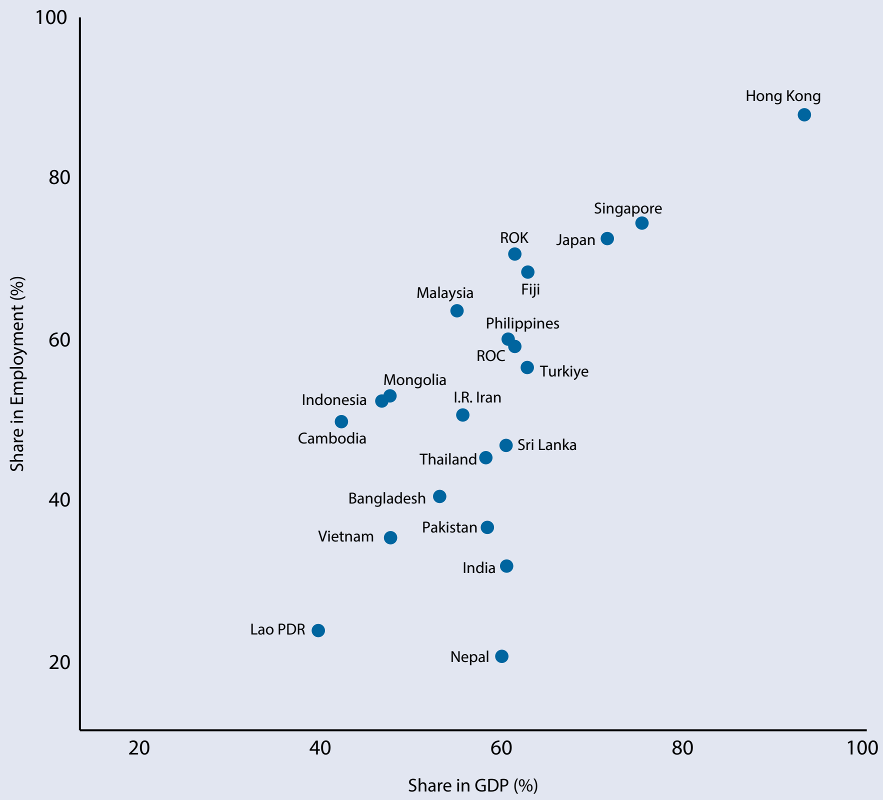
FIGURE 4-4

SHARES OF SERVICE SUB-SECTORS IN EMPLOYMENT

The relationship between the service sector's share in GDP and its share in employment reveals a clear positive correlation across various countries, as illustrated in Figure 4-5. Generally, countries with a higher service sector contribution to GDP tend to have a larger proportion of their workforce employed in the service sector. This trend is particularly evident in more developed economies. However, some interesting deviations are visible. Hong Kong and Singapore show higher GDP shares relative to employment shares, suggesting very high productivity in their service sectors. Conversely, countries like Thailand and Indonesia have lower GDP shares relative to employment shares, possibly indicating lower productivity in their service sectors.

FIGURE 4-5

SHARES OF SERVICE SECTOR IN GDP AND EMPLOYMENT IN 2019



Labor productivity in the service sector, defined as the GDP of the service sector divided by the number of employees in that sector, shows striking differences across countries, as depicted in Figure 4-6 Singapore stands out with exceptionally high productivity, more than double that of the next highest government. There's a clear divide between high-productivity countries (Singapore, Hong Kong, Japan) and lower-productivity countries (Cambodia, Lao PDR, Bangladesh). Middle-income countries show a wide range of productivity levels, suggesting varying degrees of efficiency in their service sectors.

When examining labor productivity across different service sub-sectors, Figure 4-6 reveals varied patterns. The wholesale and retail trade sector, which includes hotels and restaurants, tends to have consistent, moderate levels of productivity across most countries. The transport, storage, and communications sector show steady productivity levels, with some countries demonstrating higher output due to well-developed systems. The financial intermediation, real estate, and business activities sector stands out for its exceptionally high productivity, particularly in countries like Singapore. This highlights the crucial role that financial services, real estate, and business-related activities play in driving economic performance, especially in developed economies with strong financial sectors.

These trends collectively paint a complex picture of a service sector that is growing in importance across APO member economies, but with significant variations in its composition, employment share, and productivity levels. The data reveals clear patterns of convergence in some areas (increasing service sector shares) but persistent differences in others (productivity levels). As countries continue to develop, the service sector is likely to play an increasingly crucial role in their economic growth and development strategies. However, the path to a service-based economy is not uniform, and each government's journey reflects its unique economic structure, development stage, and policy choices.

FIGURE 4-6

LABOR PRODUCTIVITY OF SERVICE SECTOR IN 2019

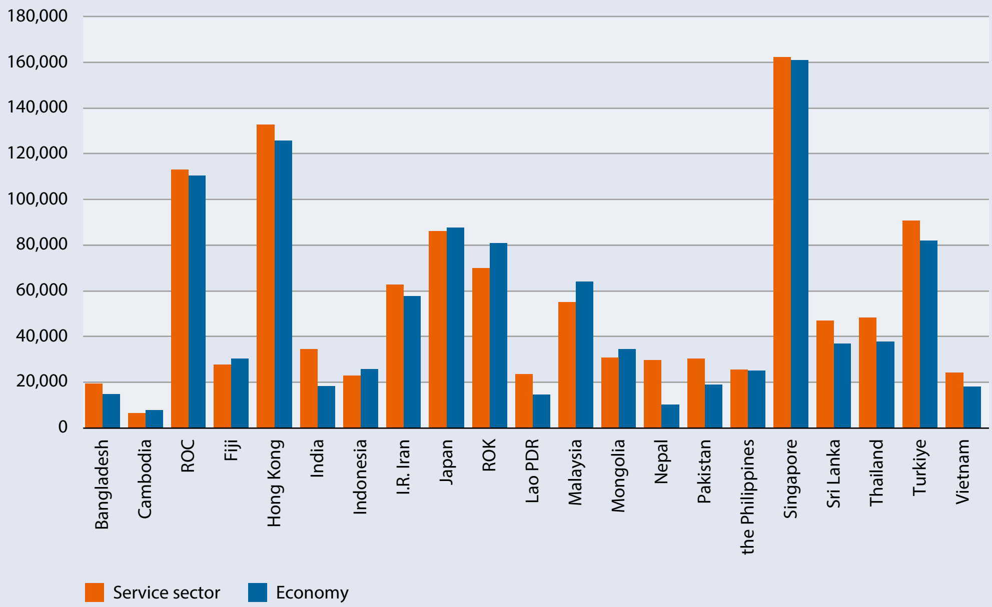
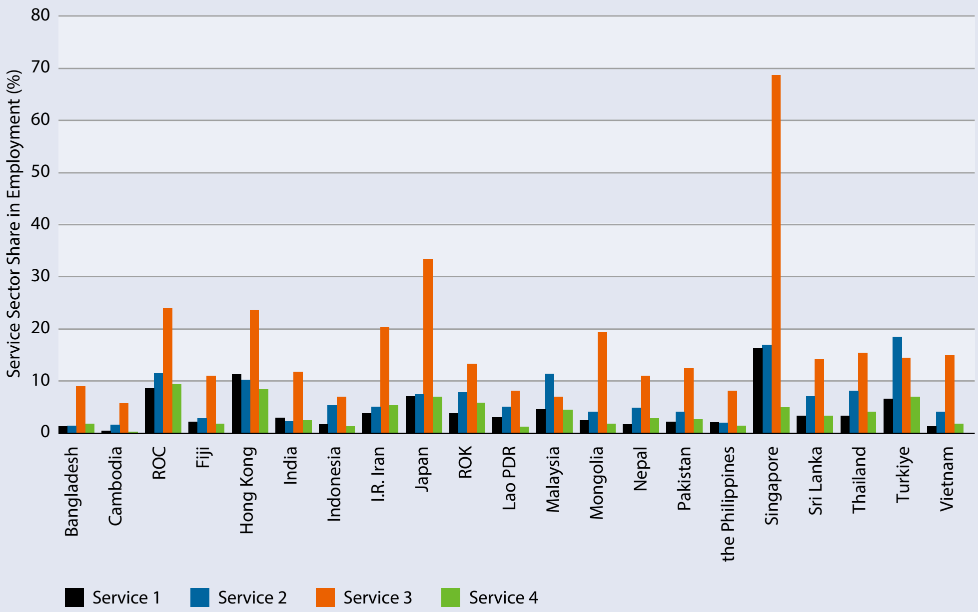


FIGURE 4-7

LABOR PRODUCTIVITY OF SUB-SERVICE SECTOR IN 2019



3) Relationship between climate and service sector productivity

The relationship between climate variables and service sector productivity is complex and nuanced, as revealed by our analysis of APO member economies from 1970 to 2019. Figure 4-8 presents a correlation matrix that explores the relationships between climate variables (temperature and precipitation) and labor productivity across different service sub-sectors. The results suggest that the direct linear relationships between climate variables and productivity are generally weak and mostly negative. Temperature shows weak negative correlations with productivity across all service sub-sectors, suggesting that higher temperatures may slightly reduce productivity, but the effect is not strong in a linear sense. Similarly, precipitation demonstrates weak, mostly negative correlations with productivity in the service sub-sectors, implying that increased rainfall might marginally decrease productivity, but the linear relationship is not strong.

Interestingly, the strongest correlations are observed between the productivity levels of different service sub-sectors, rather than between climate variables and productivity. This suggests that internal dynamics within the service sector may play a more significant role in determining productivity levels than direct climate effects. The high correlations within the service sub-sectors reflect their strong contributions to the overall service sector's productivity, highlighting the importance of specific sub-sectors like wholesale and retail trade, financial services, and community services in driving economic performance.

However, the weak linear correlations do not tell the full story. Figures 4-9 and 4-10 explore potential non-linear relationships between climate anomalies and labor productivity growth in the service sector. Figure 4-9 examines the relationship between temperature anomalies and labor productivity growth.[16] While the overall linear relationship may be weak, the scatter plots reveal more nuanced, potentially non-linear relationships in some countries. For example, countries like Fiji and Sri Lanka show evidence of a non-linear relationship, where productivity initially increases with temperature anomalies but then declines as anomalies become more extreme. By contrast, countries like I.R. Iran display a convex non-linear relationship, where labor productivity decreases more rapidly as temperature anomalies increase.

Figure 4-10 presents a similar analysis for precipitation anomalies. Again, non-linear trends are evident in some countries. Bangladesh and Sri Lanka, for example, show signs of a non-linear relationship where extreme precipitation anomalies (both positive and negative) are associated with declines in labor productivity. Other countries display more varied patterns, suggesting that the impact of precipitation on service sector productivity may be highly context dependent.

These findings highlight the importance of considering non-linear effects when analyzing the impact of climate change on service sector productivity. While simple linear correlations may not reveal strong relationships, the potential for threshold effects or tipping points in how climate variables affect productivity cannot be ignored. To further investigate these non-linear effects, our subsequent analysis will incorporate quadratic terms for temperature and precipitation in our econometric model. This approach will allow us to capture more complex relationships between climate variables and service sector productivity, providing a more comprehensive understanding of how climate change may impact economic performance in APO member economies.

16 Figures showing the relationships between climate change anomalies and labor productivity in sub-service sectors are provided in the appendix.

FIGURE 4-8

CLIMATE CHANGES AND LABOR PRODUCTIVITY (CORRELATIONS)

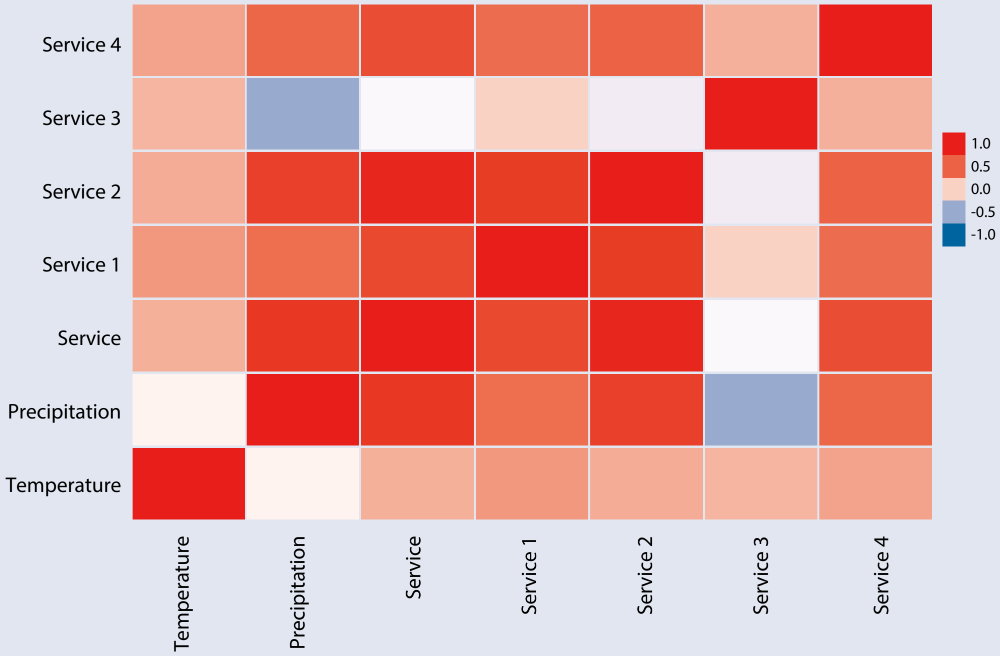


FIGURE 4-9

TEMPERATURE ANOMALY VS. LABOR PRODUCTIVITY OF SERVICE SECTOR

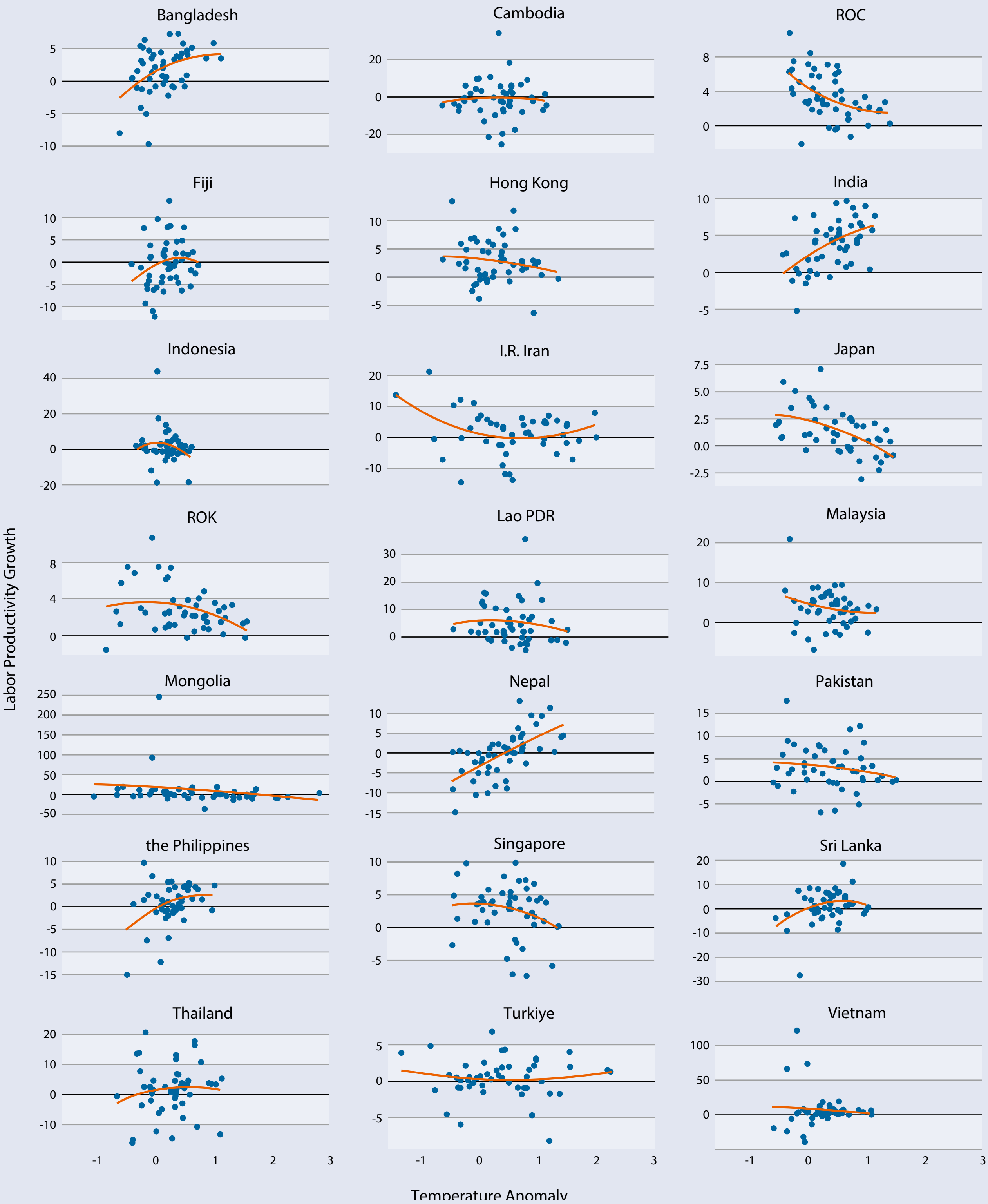
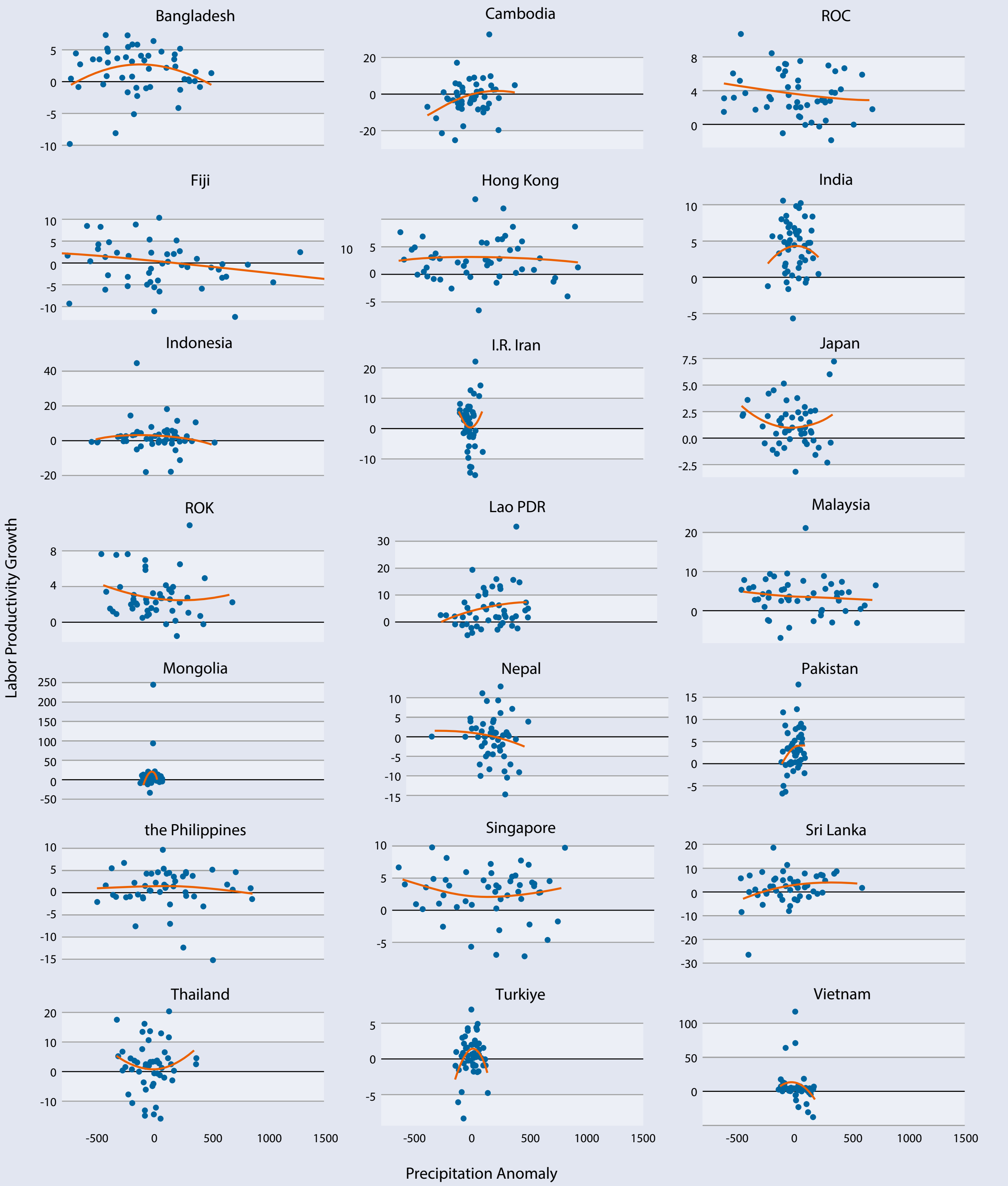


FIGURE 4-10

PRECIPITATION ANOMALY VS. LABOR PRODUCTIVITY OF SERVICE SECTOR



4. Effects on the Service Sector

The empirical methodology framework used in this chapter follows that of Burke et al. (2015) as follows:

$$\Delta A_{it}^{s} = \beta_1 T_{p,it} + \beta_2 T_{p,it}^{2} + \lambda_1 P_{p,it} + \lambda_2 P_{p,it}^{2} + \mu_i + \nu_t + \epsilon_{it},$$

where the indexation consists of two components: i for a country and t for a year. The model includes the country and year fixed effect to control the unobservable heterogeneity across country and time. Specifically, the country-specific argument, μ_i, reflects the invariant properties about socioeconomic, geographic, and cultural determinants. ν_t captures the common global effect like the sudden breakdown of the world business cycles.

A_{it}^{s} is the productivity level in the service sector and we convert it into the growth rates. T_p and P_p are the orthogonal polynomials on the climatic variables of interest, temperature and precipitation, respectively. We use climate variables as orthogonal polynomials to determine which order of climate-related variables significantly improves the model fit. This approach enhances numerical stability by reducing multicollinearity between the polynomial terms, enabling more reliable estimation without emphasizing the exact magnitude of each variable's impact.[17]

17 Time trends and their quadratic terms are used in Burke et al. (2015), but we ultimately chose not to include these variables, as there appears to be no significant unobservable linear or quadratic time trend for each economy.

TABLE 4-1

ESTIMATION RESULTS

Coefficient	Estimate	Std. Error	t-value	Pr(>t)
Dependent: whole service sector				
Temperature	-37.1110	18.3571	-2.0216	0.0435*
Temperature^2	-18.7580	13.5577	-1.3836	0.1668
Precipitation	-7.3048	12.1888	-0.5993	0.5491
Precipitation^2	-4.4722	12.8887	-0.3470	0.7287
Dependent: service sector 1				
Temperature	-47.8407	18.3964	-2.6005	0.0095**
Temperature^2	-22.6297	13.5868	-1.6656	0.0961
Precipitation	-4.0413	12.2149	-0.3309	0.7408
Precipitation^2	-5.0092	12.9163	-0.3878	0.6982
Dependent: service sector 2				
Temperature	-41.7200	20.9520	-1.9912	0.0467*
Temperature^2	-15.0390	15.4740	-0.9719	0.3314
Precipitation	-18.5270	13.9120	-1.3317	0.1833
Precipitation^2	-13.4900	14.7110	-0.9170	0.3594
Dependent: service sector 3				
Temperature	-5.6372	24.4881	-0.2302	0.8180
Temperature^2	-30.2083	18.0858	-1.6703	0.0952
Precipitation	-9.5706	16.2596	-0.5886	0.5563
Precipitation^2	31.0408	17.1933	1.8054	0.0713
Dependent: service sector 4				
Temperature	-38.6306	21.5432	-1.7932	0.0733
Temperature^2	-13.1422	15.9108	-0.8260	0.4090
Precipitation	-7.8663	14.3043	-0.5499	0.5825
Precipitation^2	-3.2314	15.1257	-0.2136	0.8309

Note. 1) Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The estimation results, as shown in Table 4-1, indicate significant impacts of climate variables on labor productivity across various service sectors in APO member economies. Since the climate-related variables are transformed into orthogonal polynomials to improve model fit, the focus is on the signs of the coefficients rather than their magnitudes.

For the overall service sector, the temperature coefficient ($T_{p,it}$) is negative and statistically significant at the 10% level. This suggests that rising temperatures are associated with a reduction in labor productivity across the service sector. The quadratic term for temperature ($T^2_{p,it}$) is also negative but not statistically significant, hinting at a potential, though weak, non-linear relationship where higher temperatures may exacerbate this negative impact.

By contrast, precipitation does not show a significant effect on overall service sector productivity, as both the linear and quadratic terms for precipitation are statistically insignificant. This implies that changes in rainfall patterns may have less direct influence on service sector productivity than temperature fluctuations.

Looking at individual service subsectors, distinct patterns emerge. Service Sector 1, which includes wholesale and retail trade, repair of vehicles and household goods, and hotels and restaurants, shows a strong negative and statistically significant relationship with temperature at the 1% level. This subsector is particularly sensitive to temperature increases, especially in tourism and hospitality, which are highly exposed to climatic variations.

Service Sector 2, which covers transport, storage, and communications, also demonstrates a negative and statistically significant relationship with rising temperatures. The impact here is similar to that in the broader service sector, with logistics and transportation being vulnerable to disruptions from extreme weather conditions.

On the contrary, the results for Service Sector 3, which includes financial intermediation, real estate, renting, and business activities, and Service Sector 4, which encompasses community, social, and personal services, show that while the temperature coefficients are negative, they are not statistically significant. This suggests that temperature changes do not strongly or consistently affect productivity in these sectors. These industries are less dependent on temperature fluctuations, as their operations rely more on economic, regulatory, and technological factors rather than climate conditions.

In summary, rising temperatures reduce labor productivity in the broader service sector, particularly in sectors that depend heavily on physical operations and human presence, such as retail, hospitality, and transport. However, sectors more insulated from physical climate impacts, such as finance and real estate, do not show significant changes.

The panel regression analysis confirms a statistically significant negative relationship between labor productivity and temperature anomalies in the overall service sector. Country-specific trends reveal some variations, with countries such as Bangladesh, Fiji, India, Nepal, and the Philippines showing positive trends in their scatter plots, suggesting that temperature anomalies might not have uniform effects across all nations. While precipitation anomalies are not statistically significant, they also seem to reduce labor productivity in the service sector. Exceptions to this trend appear in Cambodia and Pakistan; in Pakistan, limited variation in precipitation may explain the lack of significance, whereas Cambodia displays an inverted U-shaped pattern, where productivity initially increases before declining.

For specific service subsectors, temperature anomalies significantly reduce productivity in Service Sector 1 (wholesale and retail trade, hotels, restaurants, and tourism) and Service Sector 2 (transportation). These industries are particularly vulnerable to temperature changes. However, Service Sector 3 (financial intermediation, real estate) and Service Sector 4 (community, social, and personal services) are not significantly affected by temperature anomalies, likely due to their lesser dependence on climate conditions.

By employing a polynomial transformation, the panel analysis confirms a significant negative relationship between labor productivity and temperature anomalies in the service sector. However, understanding the role of deviations from long-run trends, or climate changes, requires a more refined analysis that captures the nonlinear dynamics. Therefore, I develop an alternative empirical model that focuses exclusively on the quadratic terms of temperature and precipitation anomalies, which are designed to quantify the deviations from long-term climate trends.

$$\Delta A_{it}^{s} = \beta T_{it}^{2} + \lambda P_{it}^{2} + \mu_i + v_t + \epsilon_{it}$$

TABLE 4-2

ESTIMATION RESULTS (WITH ONLY QUADRATIC TERM)

	Estimate	Std. Error	t-value	Pr(>t)
Explanatory: *Temperature*^{2}				
Whole service sector	-1.7844	0.7510	-2.3760	0.0177*
Service sector 1	-2.2464	0.7527	-2.9844	0.0029**
Service sector 2	-1.7313	0.8577	-2.0186	0.0438*
Service sector 3	-1.3895	1.0027	-1.3857	0.1661
Service sector 4	-1.5845	0.8815	-1.7975	0.0726

Note. 1) Significance codes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The results of the analysis, as shown in Table 4-2, align with the findings from the earlier model, especially for Service Sector 1 (wholesale and retail trade, tourism) and Service Sector 2 (transport, storage, and communications). In these sectors, as well as in the overall service sector, the quadratic temperature anomaly term is negative and statistically significant. This indicates that labor productivity declines as temperatures deviate from their historical norms. The statistically significant negative coefficients underscore the vulnerability of these industries to climate variability. The results suggest that higher temperatures, particularly when exceeding normal seasonal variations, have increasingly detrimental effects on productivity in these sectors.

In the case of Service Sector 1, which includes industries like tourism, retail, and hospitality, the relationship between temperature deviations and productivity losses is particularly strong. This sector is inherently sensitive to weather patterns, with industries like tourism and hospitality depending on favorable climatic conditions. The significant impact of temperature changes on this sector suggests that rising global temperatures and increased variability could substantially harm these industries' economic performances. Moreover, the strength of this relationship reflects the direct connection between temperature anomalies and customer behavior, as higher temperatures could lead to a reduction in tourism demand or a shift in tourist preferences, especially in regions heavily reliant on seasonal visitors.

Similarly, Service Sector 2, which encompasses transport, storage, and communications, shows a significant negative relationship with temperature anomalies. Rising temperatures may disrupt transportation networks, increase operational costs (such as cooling systems for transportation vehicles), and even lead to service delays caused by infrastructure vulnerabilities. For example, extreme heat can affect the efficiency of road, rail, and air transport, particularly in areas with poorly adapted infrastructure. As a result, these temperature anomalies lead to compounding inefficiencies within the transport and logistics systems, impacting overall productivity.

While Service Sector 3 (financial intermediation, real estate, and business activities) and Service Sector 4 (community, social, and personal services) do not yield statistically significant results, the negative signs on the quadratic temperature anomaly coefficients suggest some degree of sensitivity to rising temperatures. Although the effect in these sectors is not statistically strong, the negative coefficients indicate that there may still be underlying impacts from temperature anomalies that are worth further investigation. These sectors are less directly exposed to climate conditions compared to sectors like tourism or transportation; however, extreme temperature deviations could still indirectly affect them through changes in consumer demand, regulatory costs (such as energy consumption regulations), or even real estate market disruptions in affected regions.

The quadratic nature of the model emphasizes that the impact of temperature deviations is non-linear; in other words, the further temperatures deviate from historical trends, the more pronounced their negative impact becomes. This non-linearity is crucial for understanding the compounding effect of climate change on labor productivity, particularly in service-based economies where multiple sectors are interconnected. For example, a substantial temperature deviation could simultaneously impact tourism demand, transportation infrastructure, and even consumer services, leading to broader economic disruptions. This quadratic relationship suggests that climate-related challenges may escalate rapidly once temperatures reach critical thresholds, underscoring the urgency of adaptation strategies that address not only gradual warming but also the increased frequency of extreme temperature events.

In a nutshell, the results from Table 4-2 reinforce the conclusion that temperature anomalies pose a significant risk to labor productivity, especially in climate-sensitive service sectors such as tourism, hospitality, and transportation. The model's quadratic form also highlights the accelerated risks as temperature deviations increase, suggesting that future climate variability could have disproportionately large impacts on these industries if left unaddressed. While the effects on other sectors, such as finance and real estate, appear less immediate, the negative signs of the coefficients imply that even these sectors are not immune to long-term climate impacts.

5. Policy Implications: Adaptation and Mitigation Strategies

The empirical analysis presented in this study reveals significant impacts of climate change, particularly rising temperatures, on labor productivity across various service sectors in APO member economies. These findings have important implications for policymakers and business leaders as they develop strategies to address the challenges posed by climate change. This section outlines key adaptation and mitigation strategies tailored to the specific vulnerabilities identified in the service sector.

1) Adaptation strategies

Given the significant negative effects of rising temperatures on labor productivity, especially in climate-sensitive industries like tourism and transportation, immediate action is required to build resilience.

First, investing in climate-resilient infrastructure is crucial for sectors highly exposed to climate conditions, such as tourism and hospitality. This involves upgrading facilities with energy-efficient cooling systems and heat-resistant materials, implementing designs that enhance natural ventilation, and incorporating elements that reduce urban heat island effects. Urban planning should prioritize the integration of green spaces and water-efficient landscaping. These investments can help maintain operational continuity and competitiveness even under increasingly adverse climate conditions.

Second, enhancing supply chain resilience is critical for sectors like retail and transportation that are vulnerable to climate disruptions. This can be achieved by diversifying suppliers across different geographic locations and utilizing advanced technologies such as real-time data analytics and IoT devices to monitor and predict potential disruptions. Developing comprehensive contingency plans for climate-related supply chain interruptions is also essential.

Third, the development of climate insurance products can provide a financial safety net for climate-vulnerable businesses. This includes introducing parametric insurance products that offer quick payouts based on predefined climate parameters. Establishing public-private partnerships can make such insurance more accessible to small and medium-sized enterprises (SMEs). Moreover, insurance pricing mechanisms can be designed to incentivize the adoption of climate-resilient practices among businesses.

2) Mitigation strategies

While adaptation is crucial, mitigating greenhouse gas emissions remains essential for preserving long-term productivity across the service sector.

A primary mitigation strategy involves accelerating the transition to renewable energy sources. This can be facilitated through financial incentives for businesses investing in renewable energy installations, streamlining regulatory processes for renewable energy projects, and setting mandatory renewable energy usage targets for service sector businesses. Such measures can significantly reduce the sector's carbon footprint and contribute to broader climate change mitigation efforts.

Promoting energy efficiency across various industries is another vital mitigation strategy. This can be achieved through the implementation of energy management systems to monitor and optimize energy consumption in buildings and operations. Adopting energy-efficient technologies, such as LED lighting, energy-efficient appliances, and advanced heating, ventilation, and air conditioning systems, can significantly reduce energy consumption. Employee training programs focused on energy-saving practices can foster a culture of sustainability within organizations.

The adoption of low-carbon technologies, particularly in the transportation sector, can significantly reduce emissions. This involves investing in electric vehicle infrastructure, including charging stations, and prioritizing the development of electric public transport options. Governments can incentivize adoption through subsidies or tax rebates for businesses and individuals purchasing electric vehicles.

3) Policy Harmonization and Regional Cooperation

Given the interconnectedness of Asian economies, regional cooperation can enhance the effectiveness of adaptation and mitigation strategies. Collaborative efforts can involve the development of shared renewable energy grids, allowing countries to distribute energy more efficiently and reduce reliance on fossil fuels. Joint investments in research and development can accelerate the advancement of climate-resilient technologies and practices tailored to the specific needs of the Asian service sector.

Policy harmonization can also involve aligning regulations and standards related to climate change mitigation and adaptation. This alignment facilitates smoother trade relations and reduces barriers for businesses operating across borders. Regional forums and agreements can serve as platforms for sharing best practices, coordinating climate action plans, and mobilizing financial resources. International support and funding mechanisms, such as those provided by global climate funds, can be more effectively utilized when countries present unified strategies and priorities.

In conclusion, addressing the challenges posed by climate change to the service sector requires a multifaceted approach involving collaboration between governments, industry stakeholders, and international organizations. By implementing targeted adaptation strategies, pursuing aggressive mitigation efforts, and fostering regional cooperation, APO member economies can enhance the resilience of their service sectors and maintain productivity in the face of climate change. These efforts not only safeguard economic growth but also contribute to the broader goal of sustainable development in the region.

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Appendix

A1

DETAIL OF THE DATA ON SERVICE SUB-SECTORS

The analysis focuses on four distinct service sub-sectors, each encompassing a broad range of activities that contribute significantly to the economy. These sub-sectors are categorized as follows:

1) Wholesale and Retail Trade, Repair of Vehicles and Household Goods, Hotels and Restaurants

Wholesale and Retail Trade: This sub-sector includes the sale of goods in large quantities at low prices, typically to retailers or other businesses, known as wholesale trade. Retail trade involves selling goods directly to consumers. Retailers purchase products from wholesalers or manufacturers and sell them in smaller quantities to the end-users. This category is crucial for the distribution and accessibility of products to the public.

Repair of Vehicles and Household Goods: This component encompasses services for repairing and maintaining motor vehicles, such as cars and trucks, as well as repair services for various household items, including appliances, electronics, and furniture. These services ensure the longevity and functionality of personal and household assets.

Hotels and Restaurants: The hotels and restaurants category covers lodging services provided to travelers and tourists, including additional amenities like food and beverage, fitness, and recreational activities. Restaurants, ranging from fast-food outlets to fine dining establishments, prepare and serve food and beverages to customers, playing a vital role in the hospitality industry.

2) Financial Intermediation, Real Estate, Renting, and Business Activities

Financial Intermediation: This sub-sector includes banks, insurance companies, pension funds, and other financial services that facilitate the channeling of funds from savers to borrowers. It plays a critical role in maintaining the flow of capital within the economy.

Real Estate: The real estate component involves the buying, selling, renting, and managing of land and buildings, including residential, commercial, and industrial properties. This sector is integral to the development and maintenance of infrastructure.

Renting: Renting encompasses the leasing of equipment and other assets, which can range from machinery and equipment to consumer goods. This service provides businesses and individuals with access to essential tools and products without the need for ownership.

Business Activities: This broad category covers professional services such as legal and accounting services, management consultancy, advertising, market research, and technical services. It also includes administrative and support services like recruitment and facility management, which are essential for the smooth operation of businesses.

3) Transport, Storage, and Communications

Transport: The transport sub-sector includes all modes of transportation services, such as road, rail, air, and sea transport. It is vital for the movement of goods and people, facilitating trade and mobility.

Storage: Storage involves warehousing and storage services for goods, including facilities for perishable goods to raw materials. This service ensures that products are stored safely and are accessible when needed.

Communications: Communications encompass services related to the transmission of information, including telecommunications (telephone, internet, and data transmission services) and postal services. This sub-sector is fundamental for maintaining connectivity and information flow.

4) Community, Social, and Personal Services

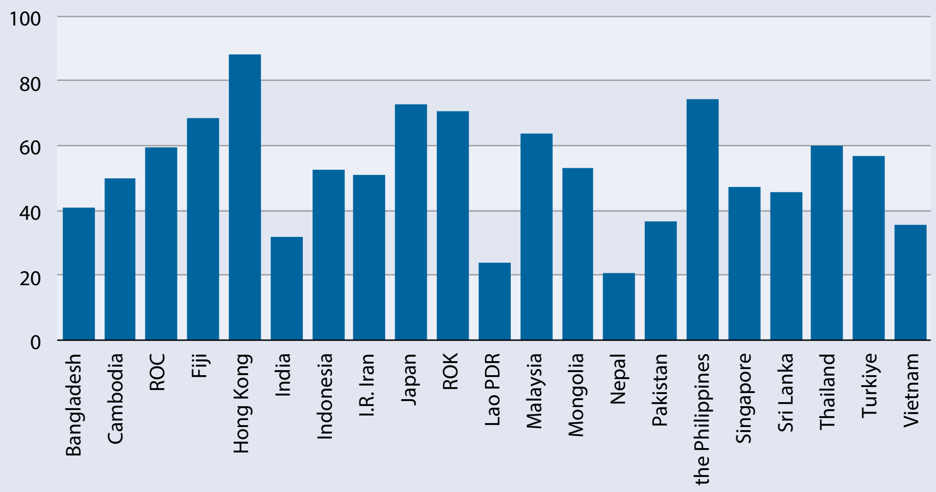
Community Services: Community services include those provided by local authorities or community organizations, such as waste management, water supply, and public safety services. These services are essential for maintaining public health and safety.

Social Services: This component encompasses a wide range of services aimed at helping individuals and families, including health services, educational services, welfare services, and social work. Social services play a crucial role in enhancing the quality of life and providing support to vulnerable populations.

Personal Services: Personal services involve meeting individual needs, such as hairdressing, beauty treatments, laundry, and cleaning services. These services contribute to personal well-being and convenience.

A2

SERVICE SECTOR SHARE IN EMPLOYMENT OF 2019



A3

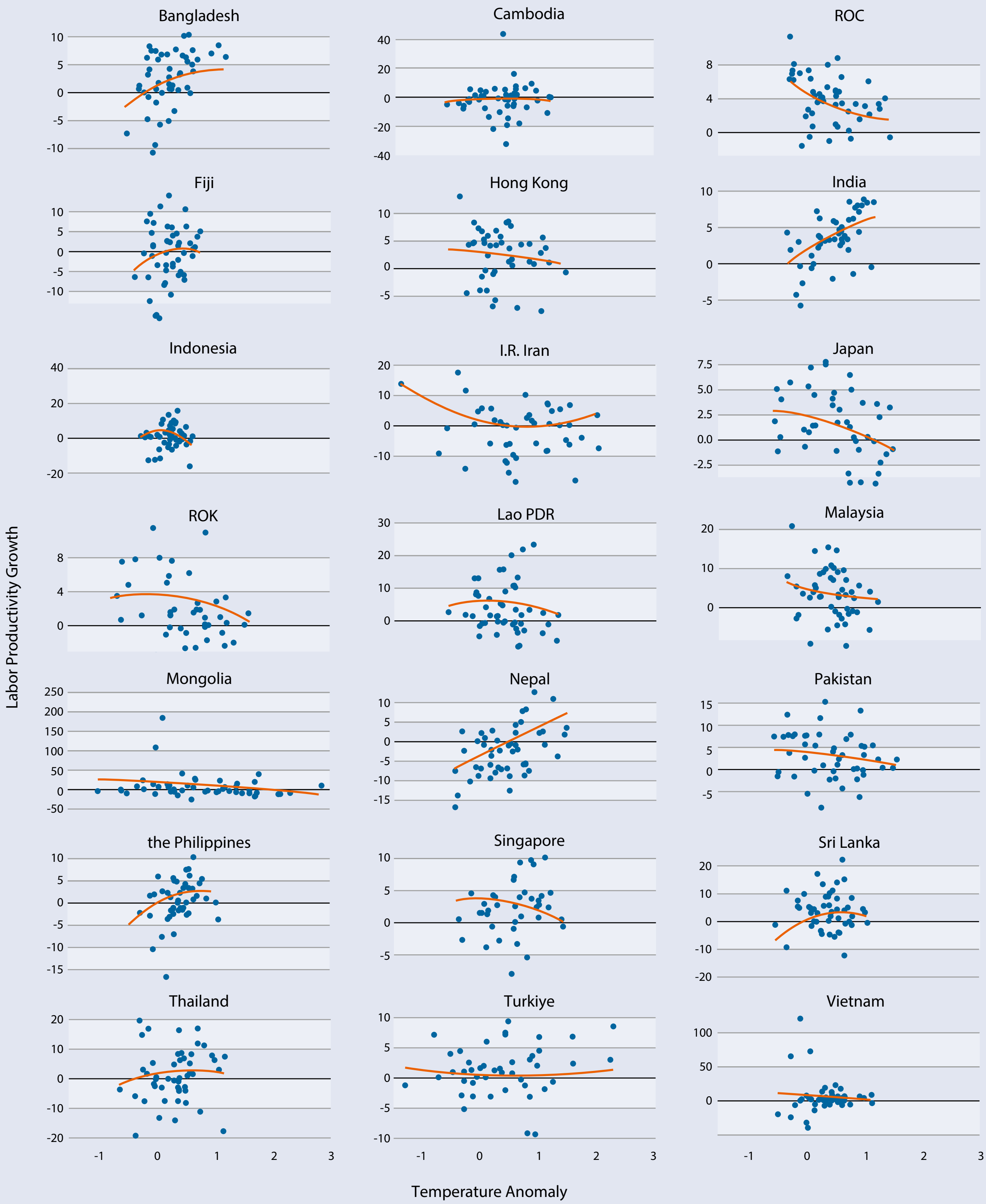
SHARES OF WHOLE SERVICE SECTOR IN EMPLOYMENT

A4

SHARES OF SERVICE SUB-SECTOR IN EMPLOYMENT

A5

TEMPERATURE ANOMALY VS. SERVICE SECTOR 1



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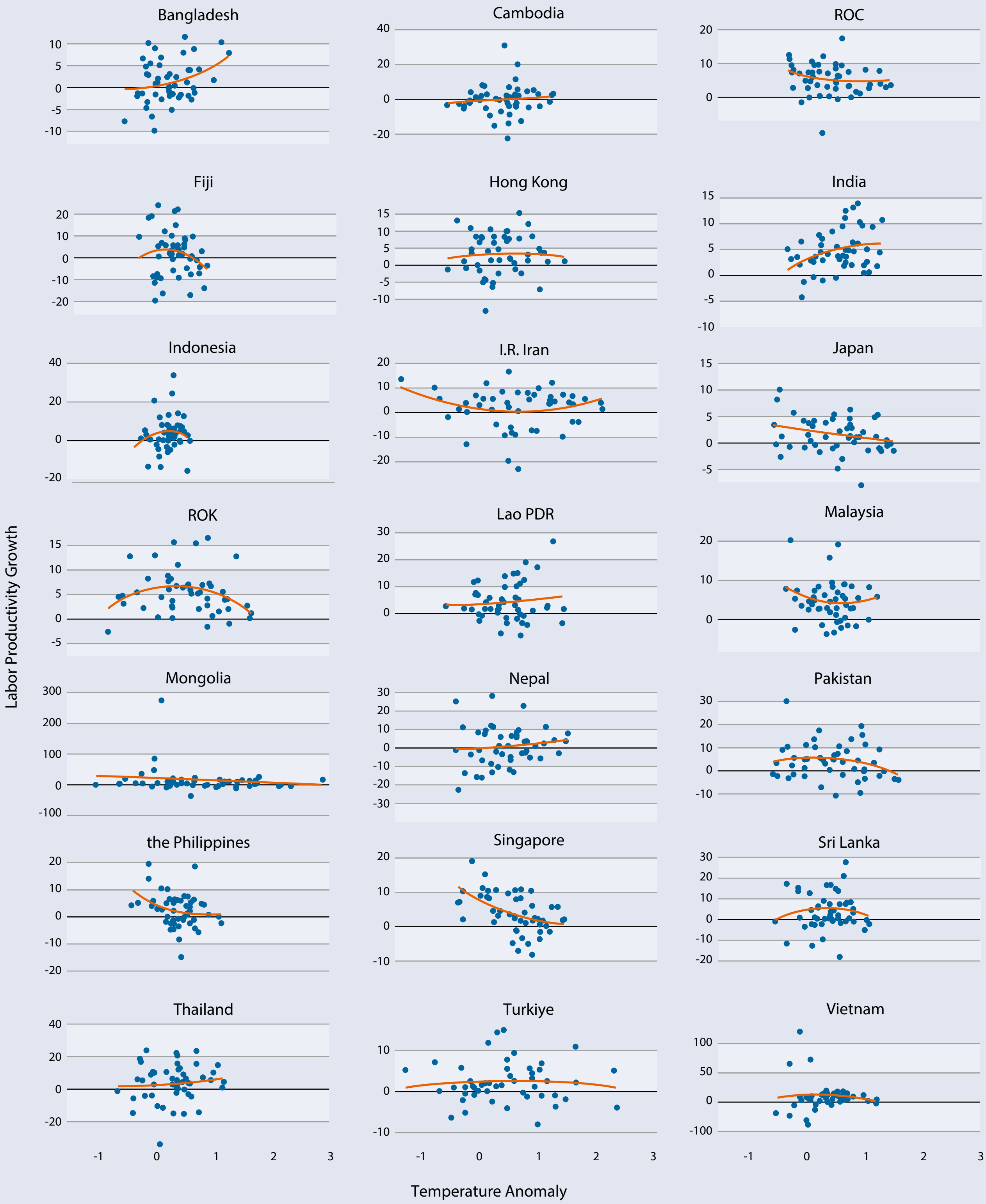
TEMPERATURE ANOMALY VS. SERVICE SECTOR 2



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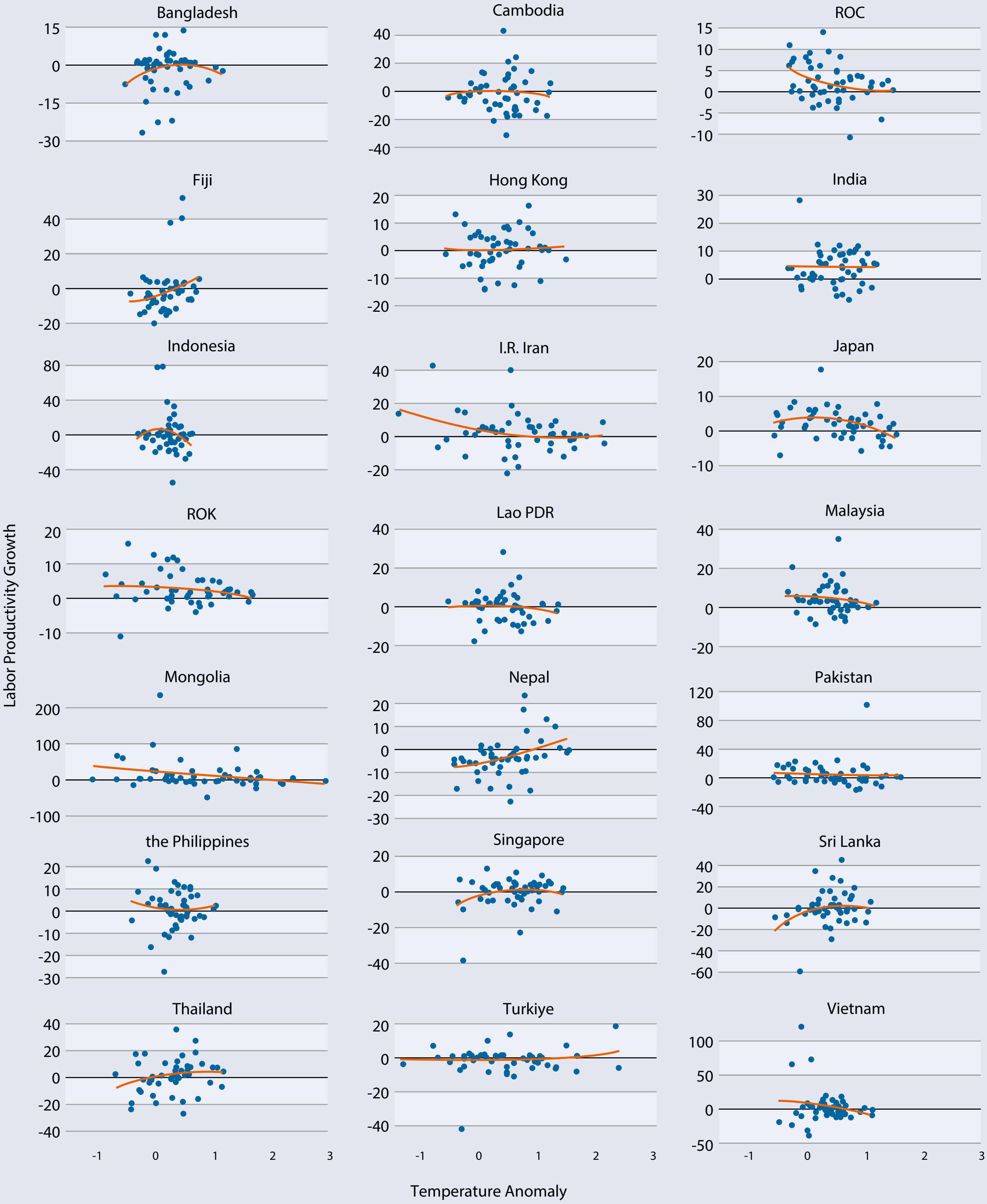
TEMPERATURE ANOMALY VS. SERVICE SECTOR 3



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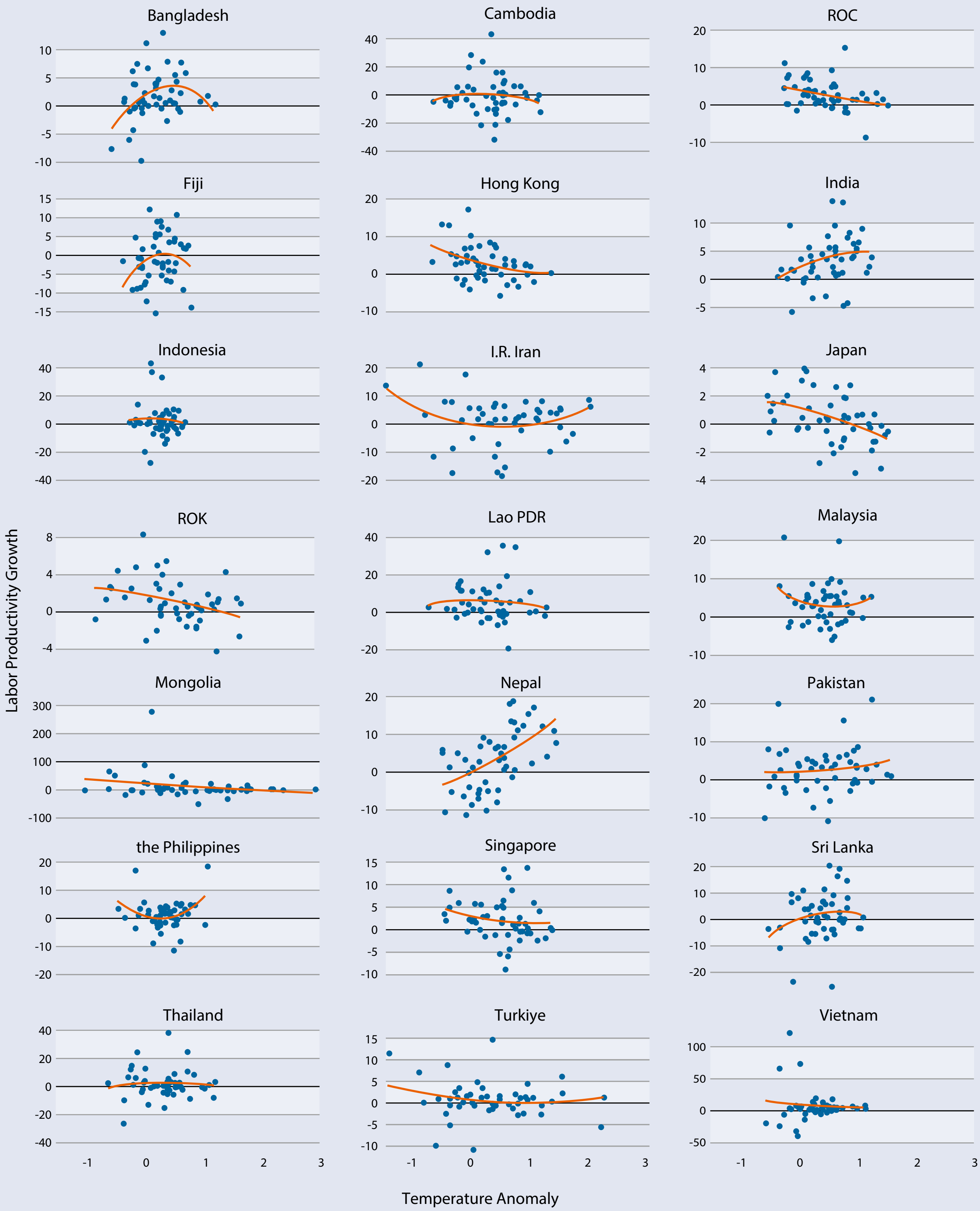
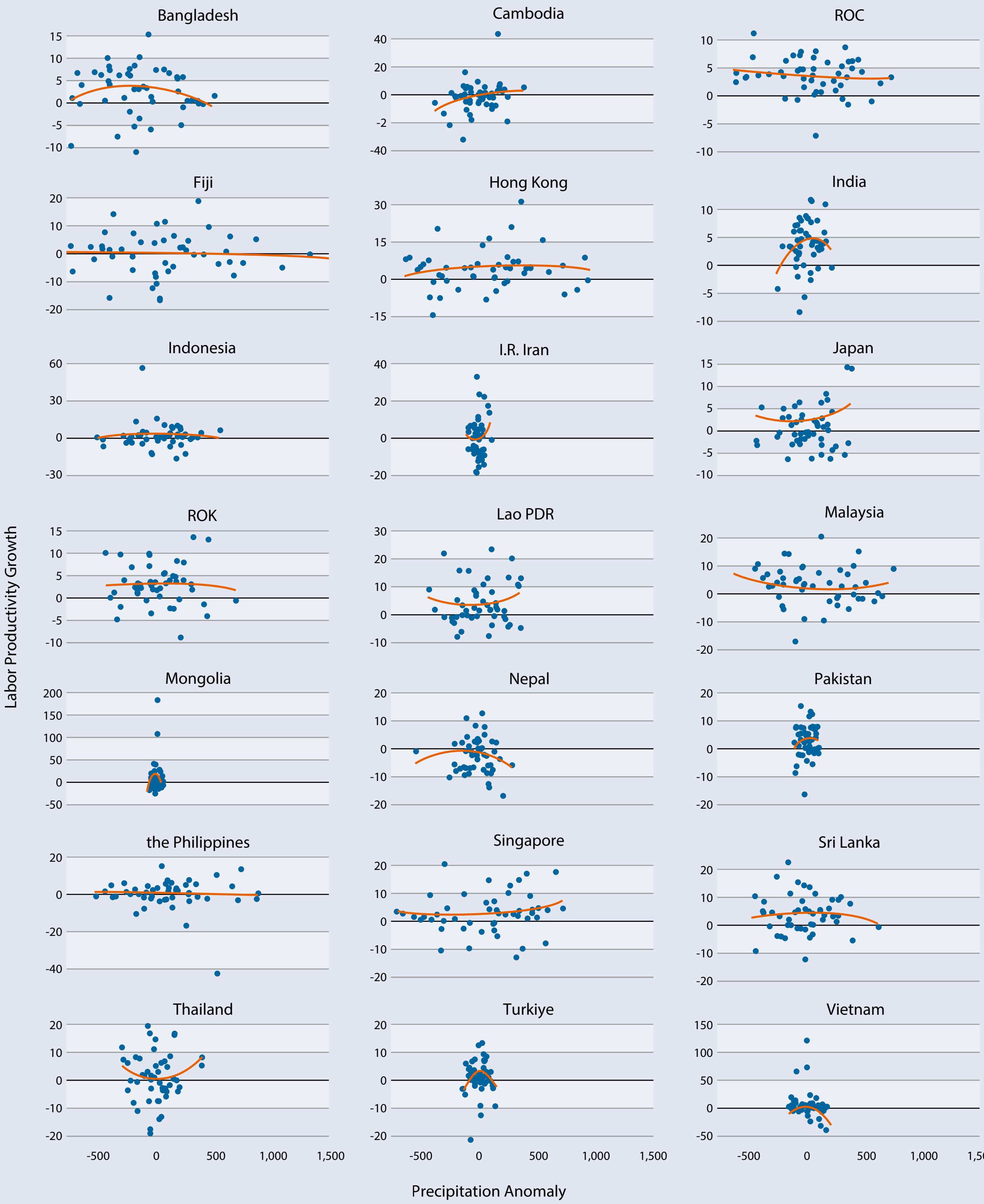
TEMPERATURE ANOMALY VS. SERVICE SECTOR 4



A9

PRECIPITATION ANOMALY VS. LABOR PRODUCTIVITY OF SERVICE SECTOR 1



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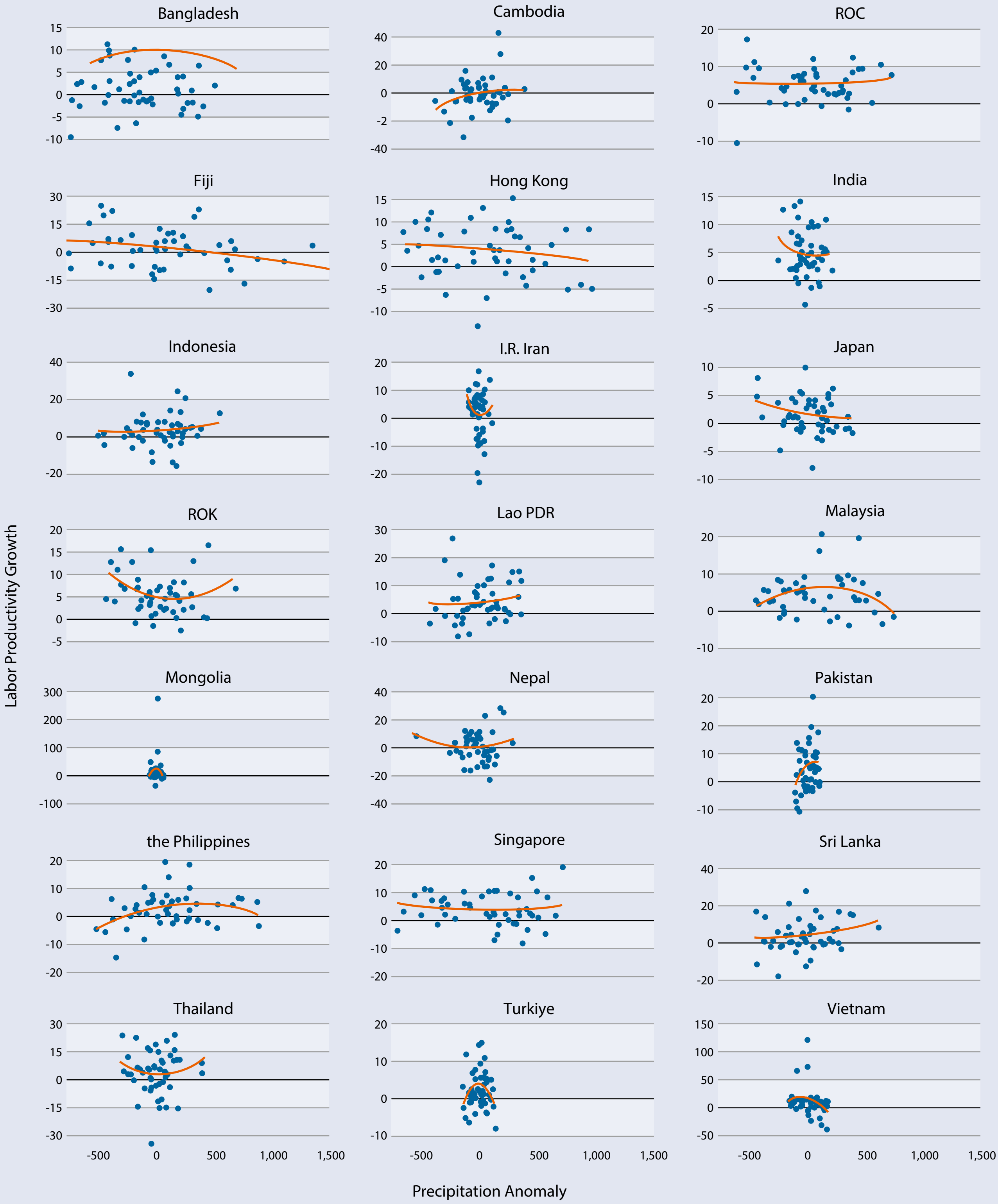
PRECIPITATION ANOMALY VS. LABOR PRODUCTIVITY OF SERVICE SECTOR 2



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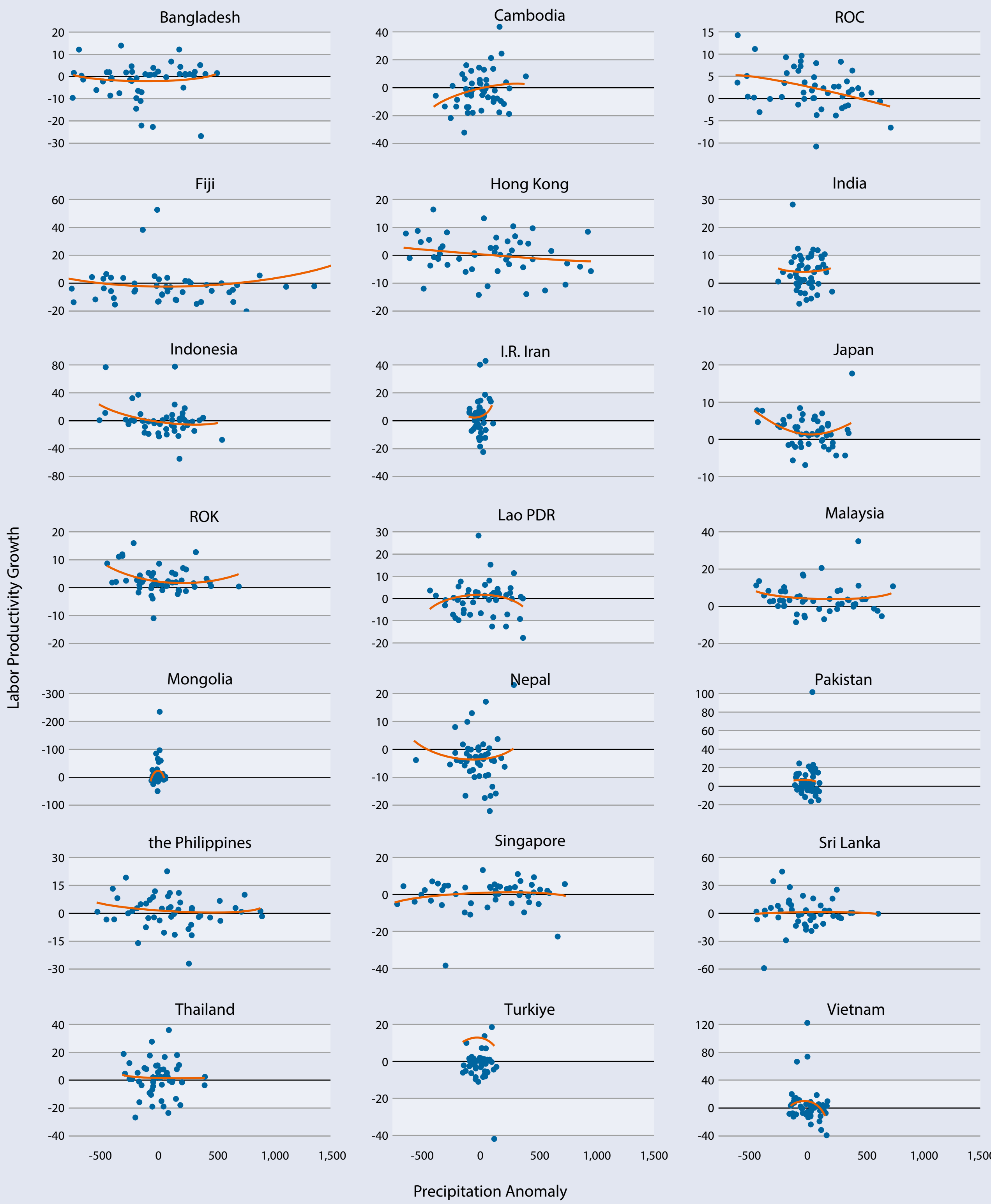
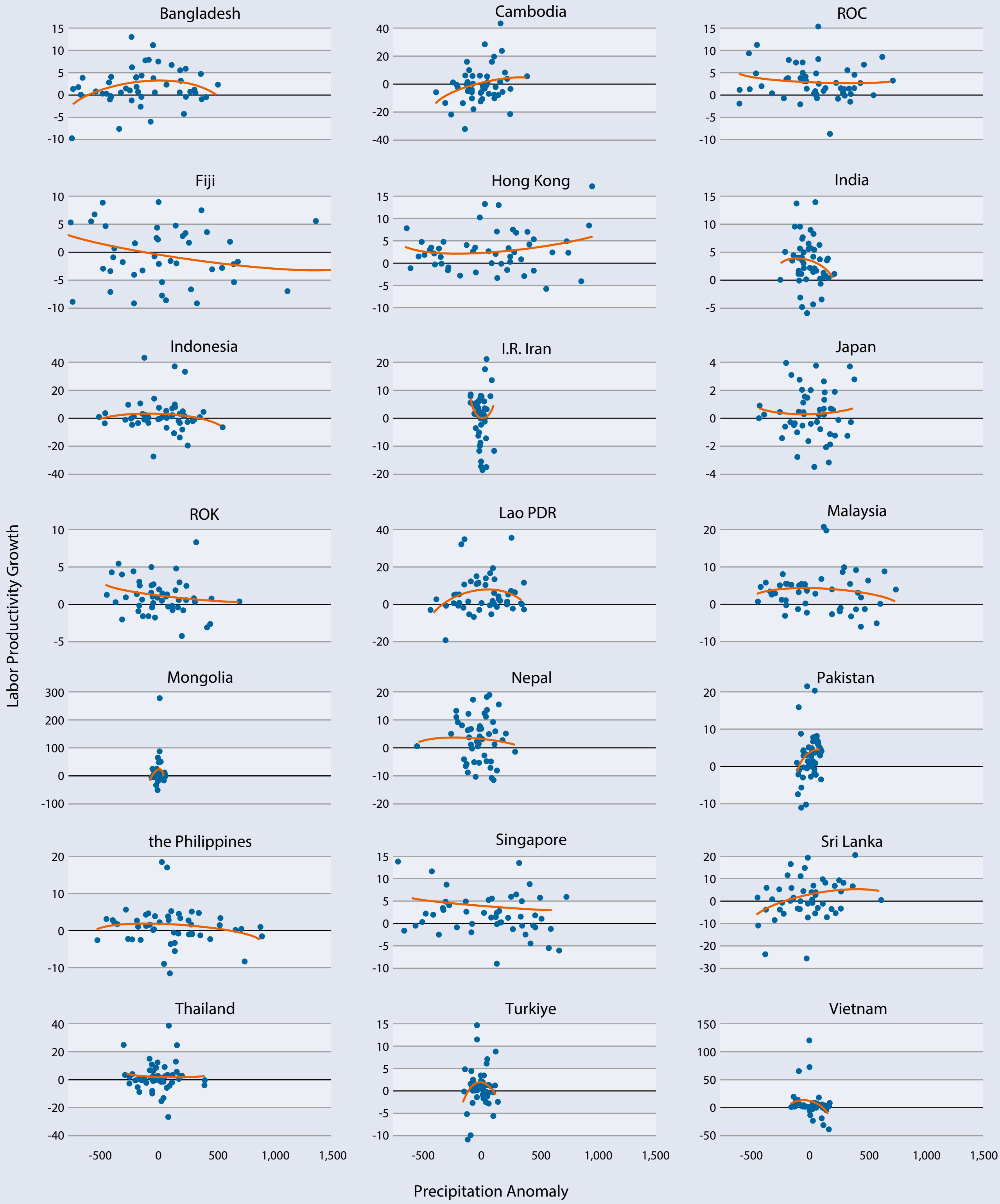
PRECIPITATION ANOMALY VS. LABOR PRODUCTIVITY OF SERVICE SECTOR 3



A12

PRECIPITATION ANOMALY VS. LABOR PRODUCTIVITY OF SERVICE SECTOR 4



CONCLUSION

The objectives of the APO Productivity Outlook 2025 are threefold. First, the report aims to identify the key channels through which climate change impacts overall productivity in APO member economies. Second, it examines the sector-specific effects of climate change on productivity, focusing on agriculture, manufacturing, and services, each of which faces distinct challenges requiring tailored analysis. Finally, the report provides evidence-based policy recommendations for mitigation and adaptation to address these challenges effectively.

Chapter 1 examines productivity trends in APO member economies, focusing on labor productivity and TFP. The analysis decomposes changes in aggregate labor productivity into structural and within-sector components and investigates the relationship between climate change and productivity. Drawing on existing research and empirical evidence, the chapter provides policy recommendations to address productivity challenges in the context of climate change. The findings reveal a statistically significant negative relationship between temperature and labor productivity in APO member economies. A 1°C increase in temperature is estimated to reduce labor productivity by 2.8% to 8.3%, depending on the estimation model. Given that average temperatures in APO members increased by 1.13°C between 1970 and 2021, this corresponds to a cumulative reduction in labor productivity of around 3.2% to 9.4%. While precipitation has a statistically significant negative coefficient, its overall impact on productivity is minimal due to regional variations. For example, countries like Singapore, Malaysia, the Philippines, and Japan experienced increases in precipitation, whereas Fiji, Bangladesh, Lao PDR, Hong Kong, and Nepal saw decreases. These contrasting patterns underscore the complex and region-specific relationship between precipitation and productivity. The cumulative impact of temperature on TFP tends to persist longer, but its magnitude is more pronounced for labor productivity, highlighting both short-term and long-term challenges posed by rising temperatures. The heterogeneity of climate change impacts across industries further emphasizes the need for a sector-specific approach to policymaking. To address these challenges, Chapters 2, 3, and 4 analyze how climate change affects productivity in agriculture, manufacturing, and services, respectively, providing tailored recommendations for each sector.

Chapter 2 focused on exploring the effects of climate change on agricultural productivity within APO members, emphasizing the critical need for both adaptation and mitigation measures. The analysis shows that temperature anomalies, where a 1-degree deviation from the average results in a 0.3% decline in agricultural productivity, pose significant challenges. High-income countries are better equipped to manage these impacts due to investments in infrastructure, advanced technology, and governance systems, which bolster climate change readiness and productivity. By contrast, low- and middle-income countries benefit most from targeted investments aimed at stabilizing climate conditions, such as irrigation systems, flood control, and drought management. This calls for adaptation strategies tailored to the unique conditions of each region. Mitigation efforts, particularly in low- and middle-income countries, face challenges as initiatives like carbon taxes and forest expansion, while addressing environmental goals, may hinder productivity due to reliance on carbon-intensive practices. To balance environmental sustainability and productivity, policymakers should promote agroforestry, low-carbon technologies, and incentives for renewable energy and precision farming tools. Recommendations include improving water management, advancing climate-resilient crops, and enhancing disaster preparedness in less developed countries, while high-income countries should focus on innovations like precision agriculture and early warning systems. Flexible carbon policies, agroforestry, and practices like no-till farming and cover cropping can contribute to sustainable agricultural productivity and long-term climate resilience.

Chapter 3 empirically examines the impact of climate change on the manufacturing productivity of APO member economies from 1970 to 2021. The regression results are as follows. First, temperature anomalies negatively impacted manufacturing productivity, particularly in lower-middle-income members. A 1°C increase led to a productivity decline of 6.9% for all members, 8.9% for upper-middle-income, and 20.9% for lower-middle-income members. High-income members showed no significant impact from temperature. Precipitation anomalies generally showed no significant effect across all income levels. Second, during the 1970s and 1980s, temperature and precipitation anomalies did not affect productivity. However, from the 1990s onwards, temperature anomalies significantly negatively affected productivity, with a 9.8% decrease in the 1990s and 2000s and a 6.2% decrease in the 2010s and early 2020s per 1°C increase. Lower-middle-income members saw a sharp increase in manufacturing share but lacked sufficient adaptability to climate change. High-income members demonstrated a robust rise in both manufacturing share and productivity, likely due to strong infrastructure and systems mitigating negative effects. Third, this chapter considers the interaction of climate change with various country characteristics, based on previous studies. Results show temperature anomalies negatively impacted productivity, but these effects were less severe in countries with higher GDP per capita, greater capital formation, and higher labor quality. In conclusion, for APO member economies, temperature anomalies consistently negatively affect manufacturing productivity, especially in lower-income countries due to insufficient adaptation capacity. Higher-income countries mitigate these effects through better infrastructure and systems. Precipitation anomalies, however, do not significantly impact productivity across APO member economies. Since manufacturing often involves indoor work, productivity changes are more related to businesses' adaptability rather than climate change itself.

Chapter 4 reveals significant impacts of climate change on service sector productivity across APO member economies, with notable heterogeneity across subsectors. Temperature deviations from long-term trends show a significant negative effect on overall service sector productivity, with the relationship exhibiting nonlinear characteristics where larger temperature anomalies lead to disproportionately larger productivity losses. The impact varies considerably across service subsectors, with wholesale/retail trade, hotels, and restaurants showing the highest sensitivity to temperature changes (coefficient of -2.2464, significant at 1% level), followed by transport and communications (coefficient of -1.7313, significant at 5% level). By contrast, financial intermediation and business services demonstrate greater resilience to temperature variations, with no statistically significant impact. Community and personal services show moderate sensitivity, though with lower statistical significance. Importantly, while temperature effects are pronounced, precipitation variations show no statistically significant impact on service sector productivity. These findings suggest that climate adaptation strategies should be tailored to specific service subsectors, with particular attention paid to temperature-sensitive industries like tourism and transportation.

Based on the findings from Chapters 1, 2, 3, and 4, we have derived the following policy implications related to adaptation and mitigation to minimize the future impacts of climate change on productivity in APO member economies.

To tackle the challenges brought about by climate variability in agriculture, policy measures must prioritize adaptation and mitigation strategies that are specifically tailored to the unique regional and economic conditions of different countries. For low- and middle-income nations, the focus should be on developing critical infrastructure, such as flood control systems, drought management solutions, and improved irrigation technologies, to stabilize climate impacts and boost agricultural productivity. Meanwhile, high-income countries should concentrate on advancing climate-resilient agriculture by investing in resilient crop varieties, cutting-edge irrigation systems, and durable agricultural infrastructure. Adaptation efforts must also include enhancing water management, constructing resilient systems, and providing farmers with education and awareness programs to better equip them for managing climate-related risks. On the mitigation side, policies should strike a balance between achieving environmental goals and maintaining agricultural productivity by adopting flexible carbon taxation systems and promoting low-carbon innovations. Core strategies include minimizing greenhouse gas emissions from livestock, utilizing sustainable soil management practices, fostering agroforestry and reforestation efforts, and increasing energy efficiency in agricultural operations through renewable energy solutions and precision farming. By combining these approaches, policymakers can strengthen agricultural resilience while addressing the dual goals of adaptation to and mitigation of climate change impacts.

For adaptation policies in the manufacturing sector, the APO should focus on improving infrastructure and facilities like heating and cooling systems and indoor workplaces, enhancing technology levels, and improving workers' skills through education and job training, especially in developing countries. For example, there is a disparity in electric power consumption among income groups, indicating a large gap in adaptive capacity. This supports the need for cooperation between APO's adaptation strategy and ODA projects, alongside a long-term vision for climate change response. For mitigation policies, the APO should focus on transiting production facilities from traditional methods to eco-friendly systems, such as solar power generators, particularly in developed countries. In addition, the APO should focus on strengthening environmental regulations in manufacturing and supporting certification systems and infrastructure, especially in developing countries. There is a need for APO's mitigation strategies to align with ODA projects, in addition to adaptation strategies, to improve environmental regulation implementation in developing countries.

To address the significant challenges posed by climate change in the service sector, both adaptation and mitigation strategies are essential. Adaptation strategies should focus on investing in climate-resilient infrastructure, enhancing supply chain resilience, and developing accessible climate insurance products to support businesses vulnerable to climate disruptions. These measures can ensure operational continuity and competitiveness under adverse conditions. On the mitigation front, transitioning to renewable energy, promoting energy efficiency, and adopting low-carbon technologies, particularly in transportation, are critical for reducing greenhouse gas emissions and preserving long-term productivity. Policies such as financial incentives for renewable energy adoption, support for energy-efficient technologies, and subsidies for electric vehicles can facilitate these transitions, fostering sustainability and resilience in the service sector.

APO plays a vital role in helping its members mitigate the impact of climate change on productivity. Through its Green Productivity initiative, APO promotes practices that not only drive productivity growth but also reduce environmental impact. This initiative encourages industries to adopt eco-friendly and sustainable methods, ensuring that economic progress is aligned with environmental preservation. Finally, APO fosters enhanced cooperation among its members, promoting regional collaboration and the sharing of resources and best practices to effectively combat the challenges posed by climate change.

TABLE 5-1

ADAPTATION AND MITIGATION STRATEGIES FOR CLIMATE-RESILIENT PRODUCTIVITY ACROSS SECTORS

Sectors	Adaptation	Mitigation
Agriculture	• Increase adaptation investments in low- and middle-income economies: focus on infrastructure like flood control and drought management to improve climate stability and agricultural productivity • Support climate-resilient agriculture in high-income economies: invest in resilient crops and irrigation systems to mitigate the effects of temperature anomalies and enhance productivity • Adaptation policy suggestions: 1) Development and dissemination of climate-resilient crops, 2) Improvement of water management and irrigation system, 3) Building resilient agricultural infrastructure, 4) Agricultural education and awareness programs	• Tailor mitigation policies to minimize negative impacts: Adjust carbon taxes and promote low-carbon technologies to balance environmental goals with maintaining agricultural productivity • Mitigation policy suggestions: 1) Reducing greenhouse gas emissions from livestock, 2) Sustainable soil management, 3) Agroforestry and reforestation, 4) Energy efficiency in agriculture
Manufacturing	• Build infrastructures and facilities such as heating and cooling systems, and indoor workplaces in manufacturing • Support education and job training programs to improve labor quality in manufacturing • These policies should be focused on developing countries	• Change manufacturing production facilities using from traditional method to eco-friendly green system such as solar light power generators, especially in developed countries • Support certification systems and infrastructures to tighten environmental regulations in manufacturing production, especially in developing countries
Service	• Invest in climate-resilient infrastructure • Enhance supply chain resilience • Develop climate insurance products	• Accelerate transition to renewable energy • Promote energy efficiency across industries • Adopt low-carbon technologies in transportation

COUNTRY PROFILES

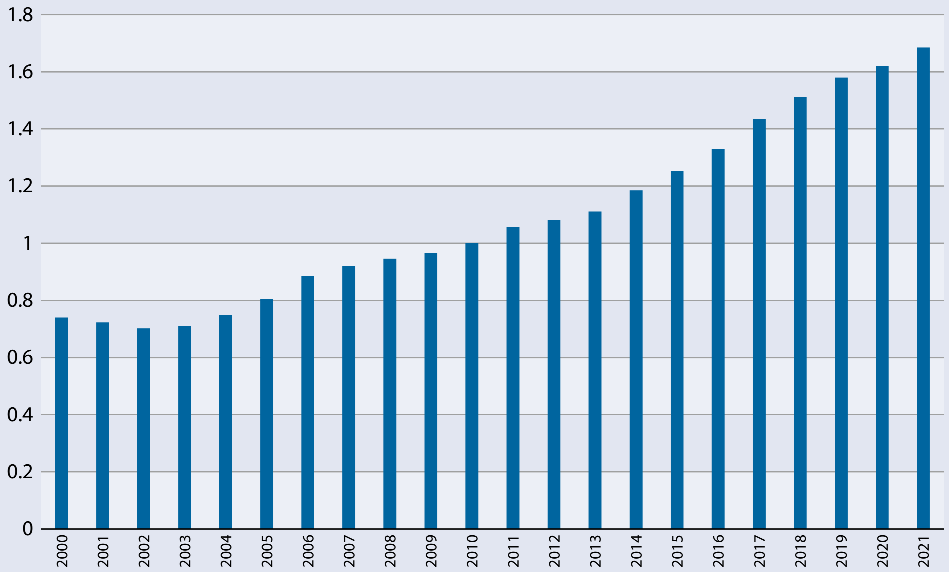
COUNTRY PROFILE: BANGLADESH

<Agriculture>

- In Bangladesh, agricultural labor productivity has steadily increased since the 2000s. By 2021, it showed significant improvement compared to 2016.

FIGURE 1

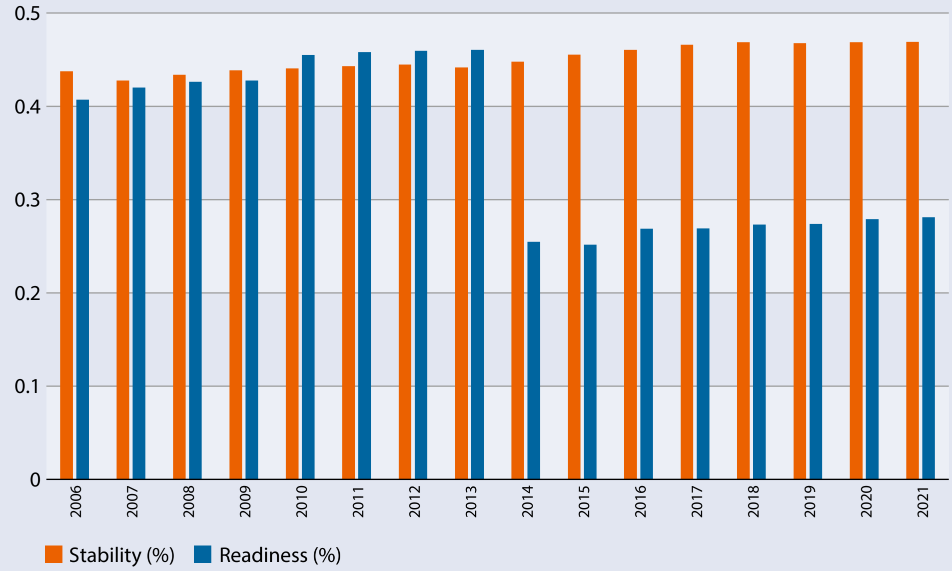
AGRICULTURAL LABOR PRODUCTIVITY



- Bangladesh shows a moderate level of Stability with a relatively steady Readiness score over time. There have been slight improvements in Readiness since 2000.

FIGURE 2

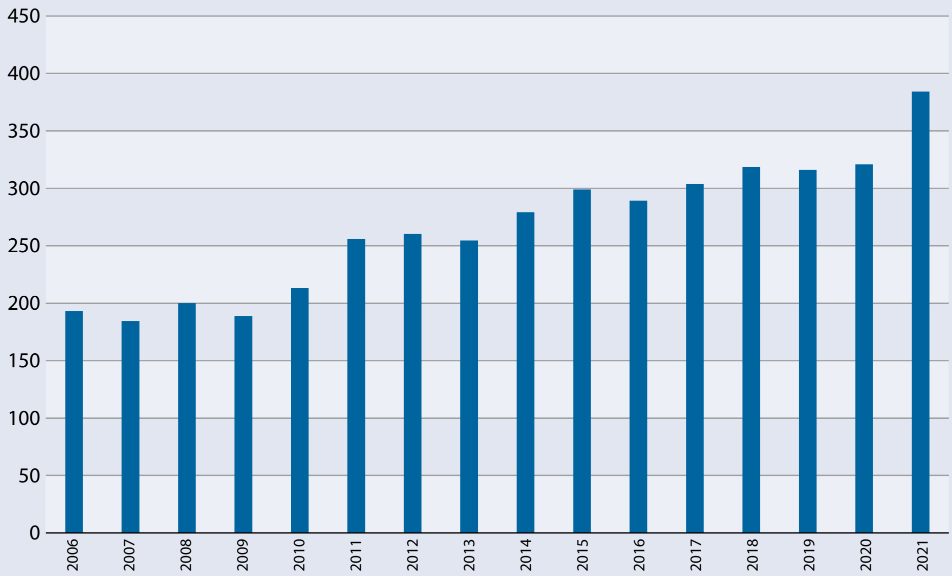
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Fertilizer consumption in Bangladesh has gradually increased over the years, with a noticeable rise after 2015.

FIGURE 3

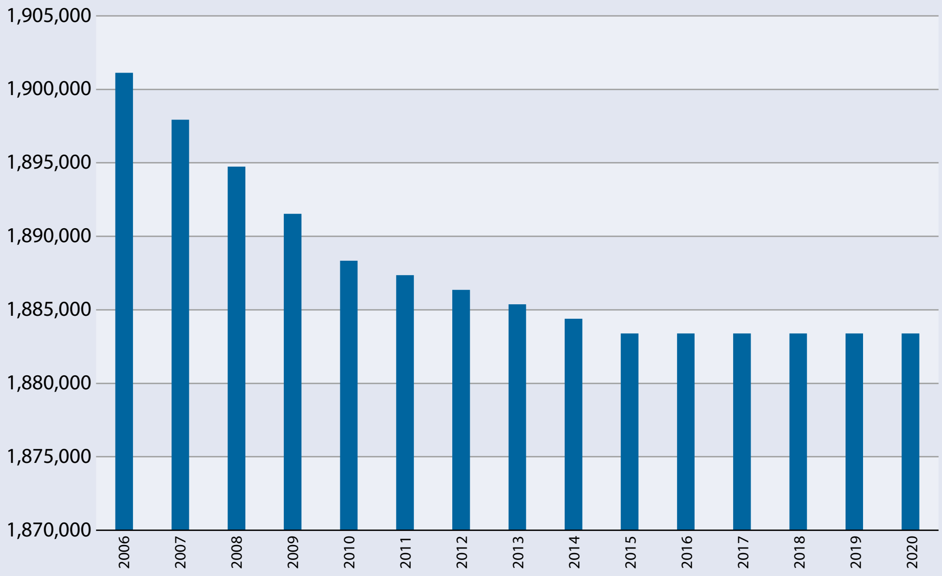
FERTILIZER CONSUMPTION



- Bangladesh's forest area has gradually declined since 2000, showing a steady decrease over the years.

FIGURE 4

FOREST AREA

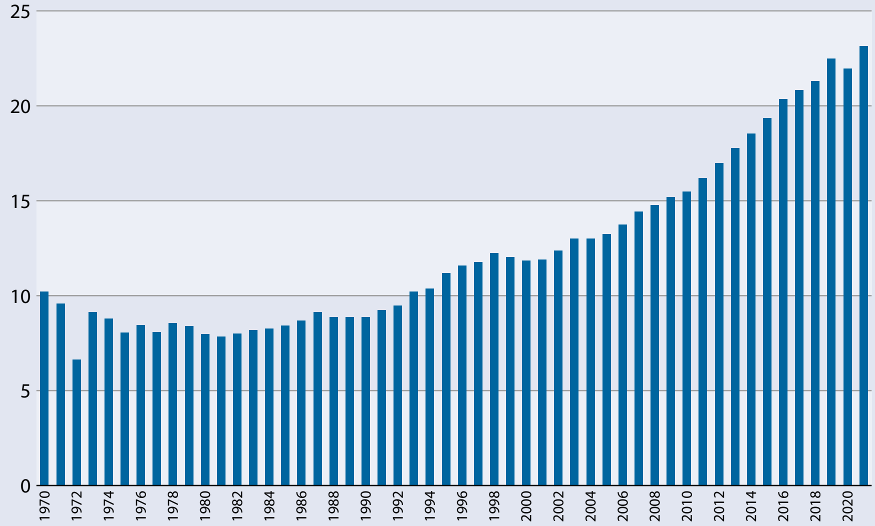


<Manufacturing>

- The trend shows fluctuations with periods of growth, likely due to industrial expansion and policy shifts between 1970 and 1990. However, it has shown a steadily increasing trend since 1990, reaching its highest level in 2021.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

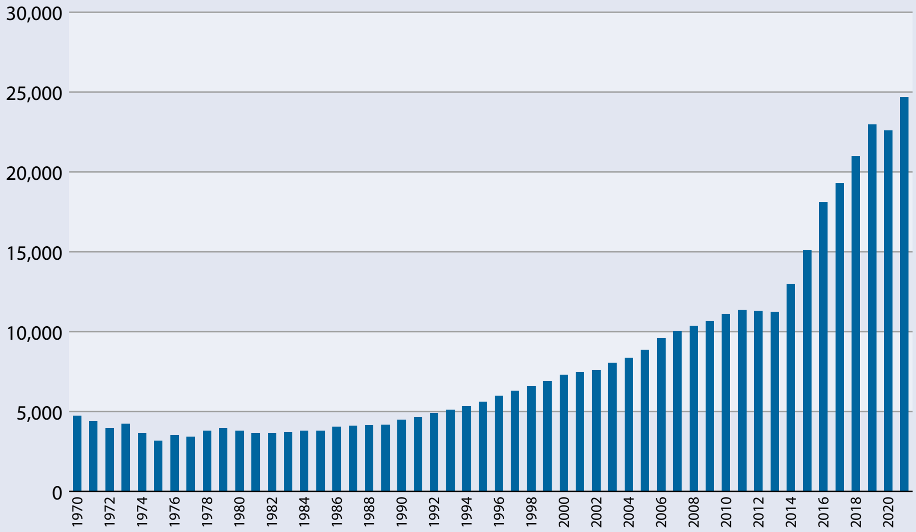


Source: Author's calculations based on the APO Productivity Database

- Similar to the share of manufacturing in GDP, labor productivity has shown a steadily increasing trend since 1990, with a particularly sharp increase since 2014, reaching its highest level in 2021. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



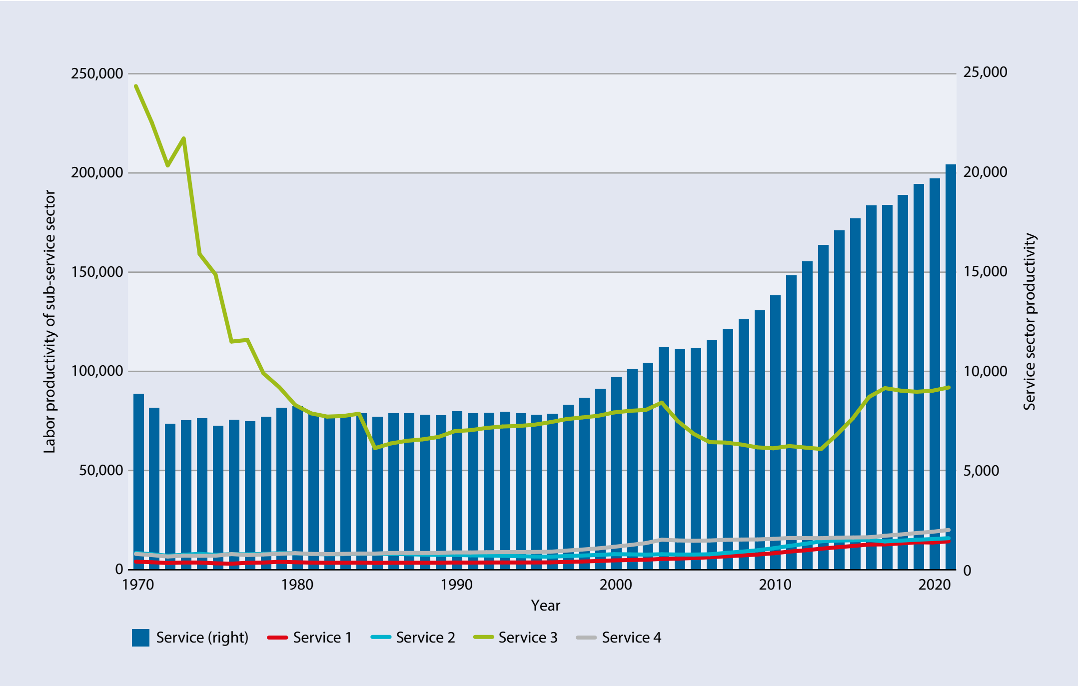
Source: Author's calculations based on the APO Productivity Database

<Service>

- The overall productivity of Bangladesh's service sector has shown gradual growth over time, with an initial lower productivity level that steadily increased from the 1990s onward.

- Service Sector 3 (finance, real estate, renting, and business activities) initially exhibited high labor productivity at approximately 250,000. However, it experienced a sharp decline until the mid-1980s, after which its productivity stabilized at around 100,000, and it maintained this level through 2020.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), have exhibited minimal labor productivity changes, maintaining low levels overall with minor upward trends in recent decades.



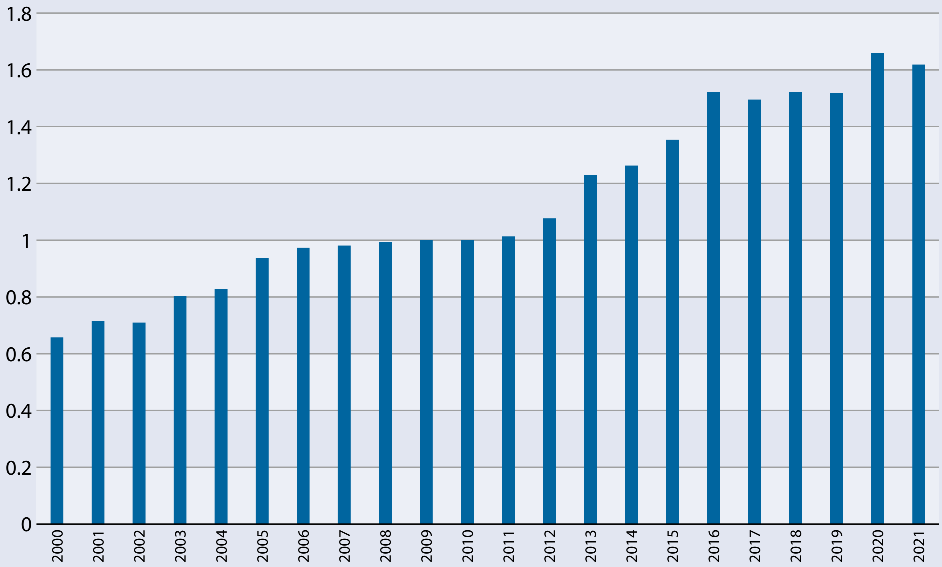
COUNTRY PROFILE: CAMBODIA

<Agriculture>

- Cambodia's agricultural labor productivity has shown a steady increase since the early 2000s. This stable growth continued consistently through 2021.

FIGURE 1

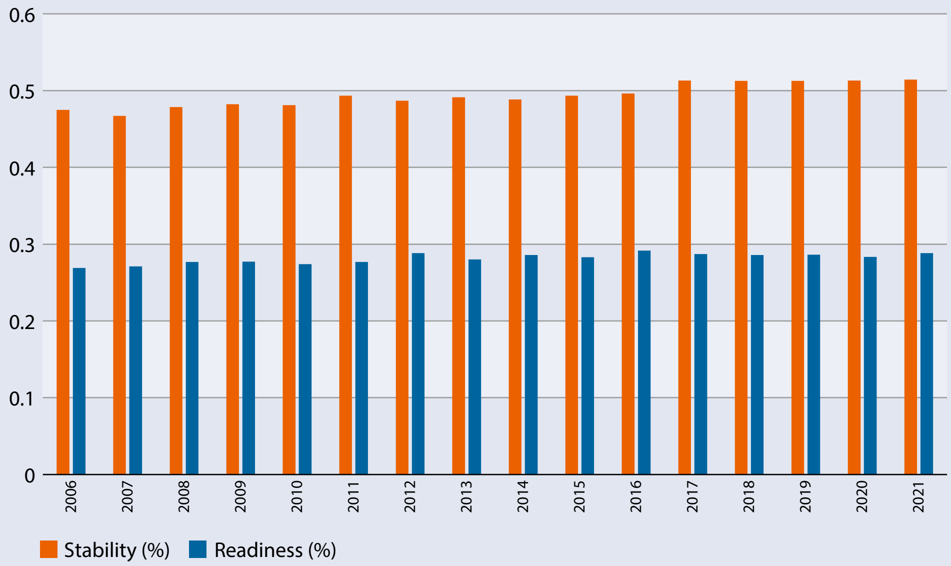
AGRICULTURAL LABOR PRODUCTIVITY



- Cambodia shows steady Stability scores, with Readiness remaining relatively stable as well, suggesting a balanced approach to climate adaptation.

FIGURE 2

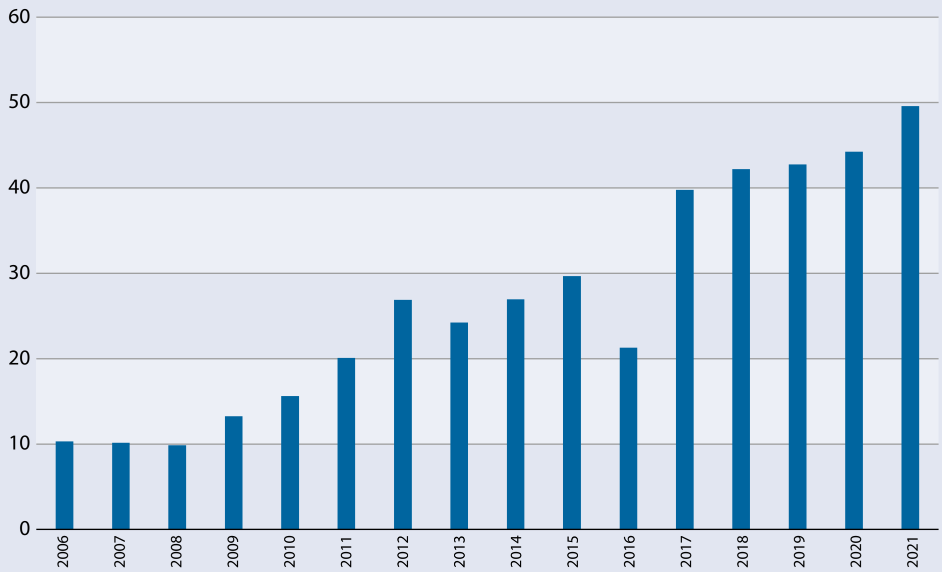
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Cambodia shows a sharp increase in fertilizer use, especially from 2010 onward, reflecting substantial growth in agricultural inputs.

FIGURE 3

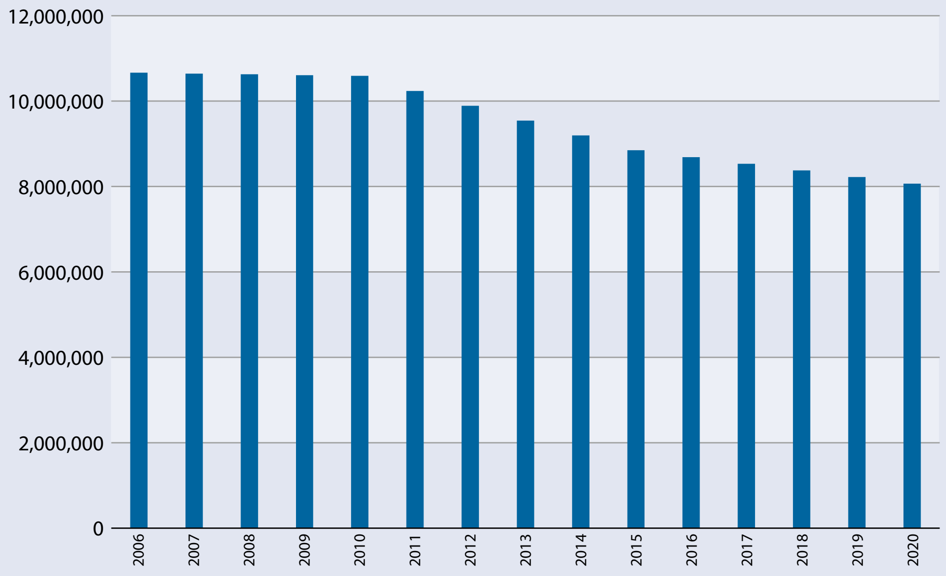
FERTILIZER CONSUMPTION



- Cambodia's forest area has decreased steadily, with noticeable deforestation over the years.

FIGURE 4

FOREST AREA

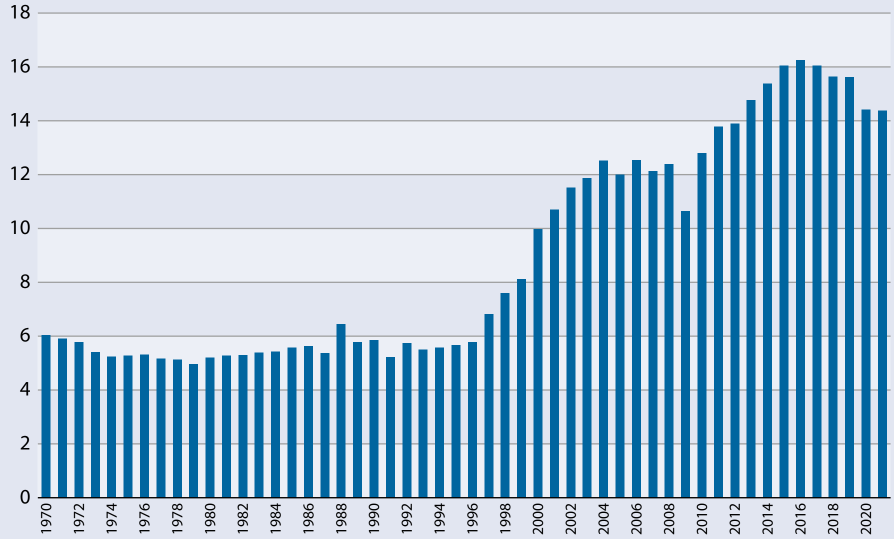


<Manufacturing>

- Cambodia's manufacturing showed a relatively steady trend until 1997, then began to increase sharply in the 2000s. However, after reaching its peak in 2017, it has shown a slight downward trend through 2021.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

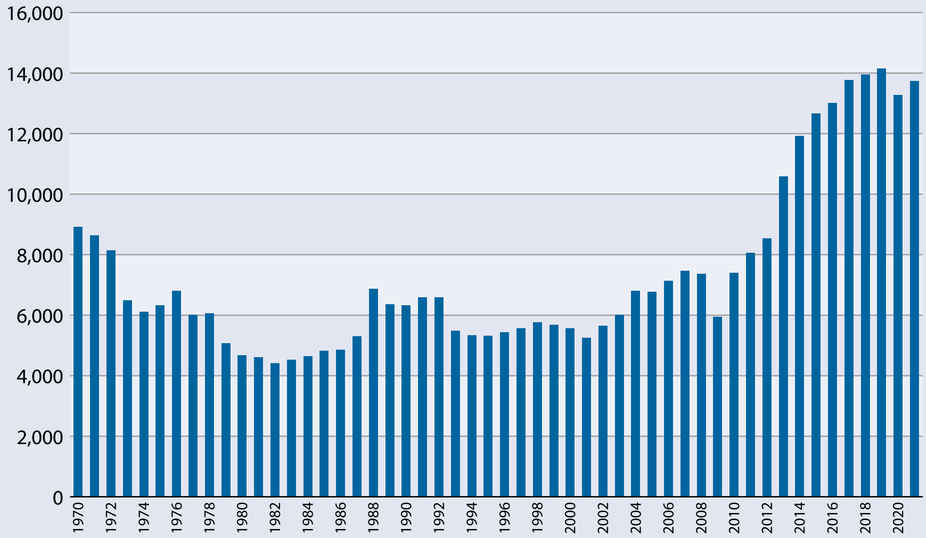


Source: Author's calculations based on the APO Productivity Database

- Unlike the trend in the share of manufacturing in GDP, labor productivity fluctuated between ups and downs from 1970 to 2010. However, it has shown a sharply increasing trend since the 2010s. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



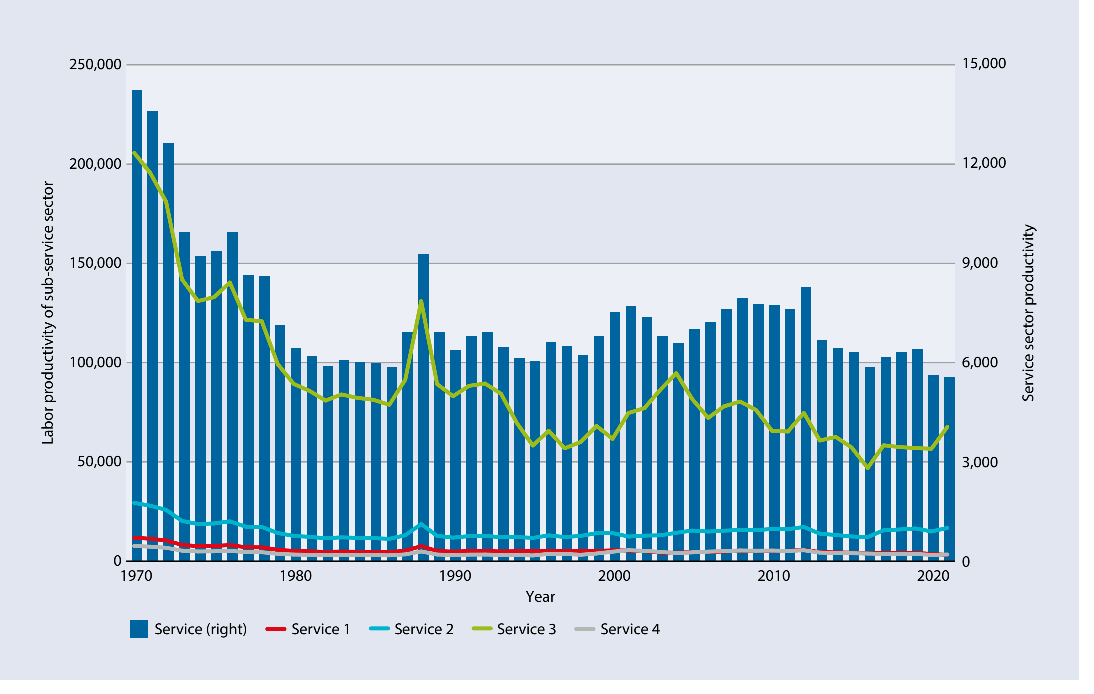
Source: Author's calculations based on the APO Productivity Database

<Service>

- The service sector in Cambodia experienced a significant initial decline from a high productivity level in the early 1970s, continuing the gradual declining pattern afterward, stabilizing at a much lower level in the mid-1980s.

- Service Sector 3 (finance, real estate, renting, and business activities) initially exhibited high labor productivity at approximately 200,000 but experienced a sharp decline, followed by a gradual downward trend over the past several decades.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), consistently maintained relatively low labor productivity levels over the entire period.



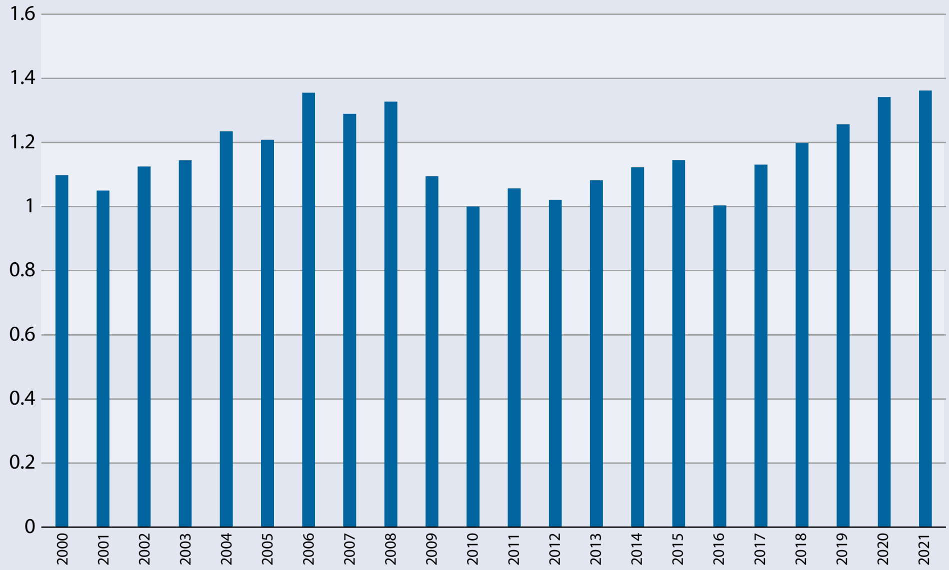
COUNTRY PROFILE: FIJI

<Agriculture>

- Fiji's labor productivity in agriculture displays a gradual upward trend. Despite minor fluctuations after 2016, productivity has remained stable.

FIGURE 1

AGRICULTURAL LABOR PRODUCTIVITY



- In Fiji, Stability remains consistent, while Readiness has shown gradual fluctuations. Both variables maintain a relatively steady level across the years.

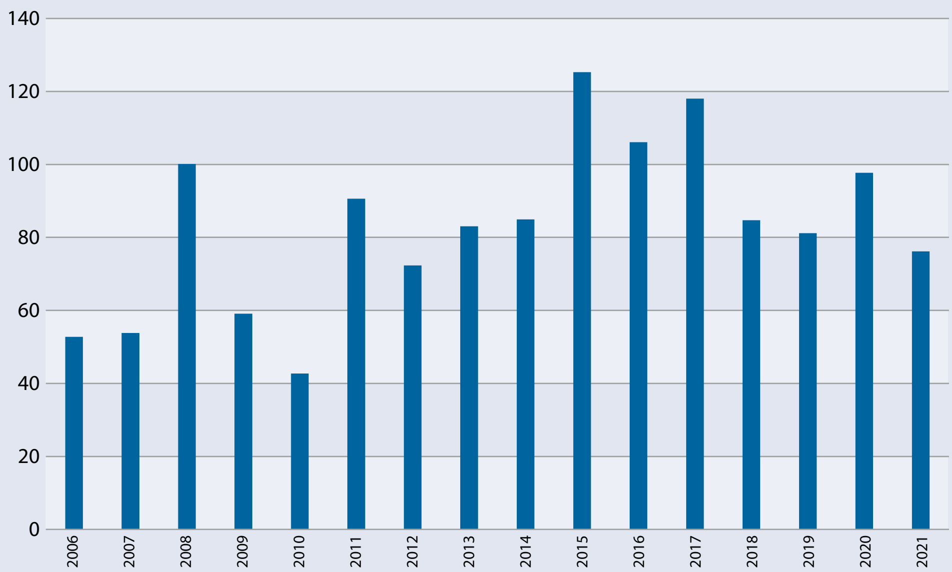
FIGURE 2

CLIMATE CHANGE ADAPTATION: STABILITY, READINESS

- Fiji's fertilizer use shows moderate fluctuations, with an overall steady trend and occasional peaks throughout the years.

FIGURE 3

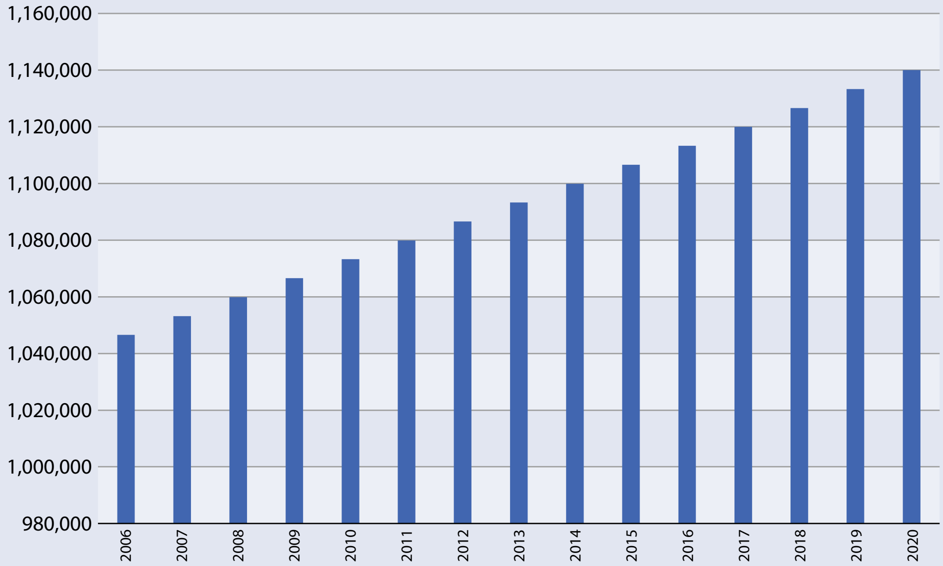
FERTILIZER CONSUMPTION



- Fiji shows a gradual increase in forest area, with consistent growth observed throughout the period.

FIGURE 4

FOREST AREA

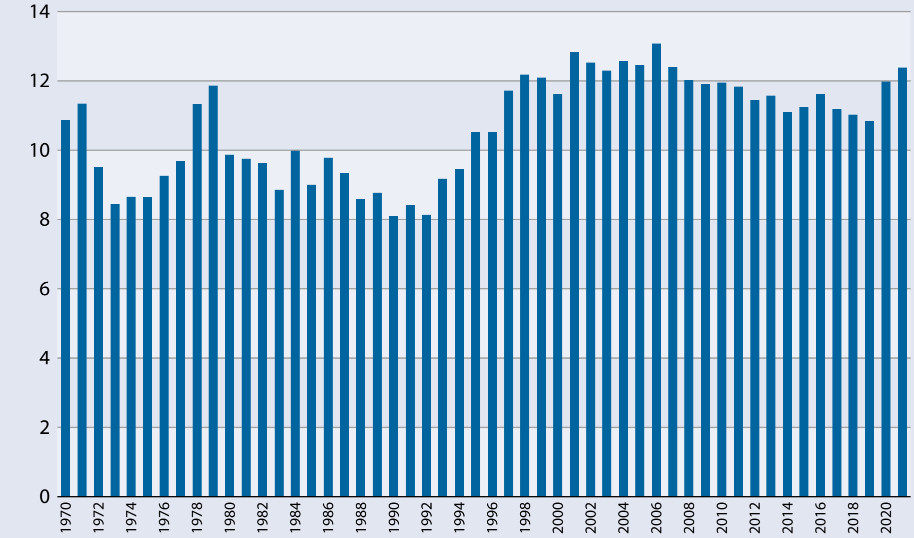


<Manufacturing>

- From 1970 to the early 1990s, Fiji's manufacturing showed a trend of fluctuations, then began to increase. However, in the 2010s, it showed a decreasing trend. Now in the 2020s, it has shown a rebound.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

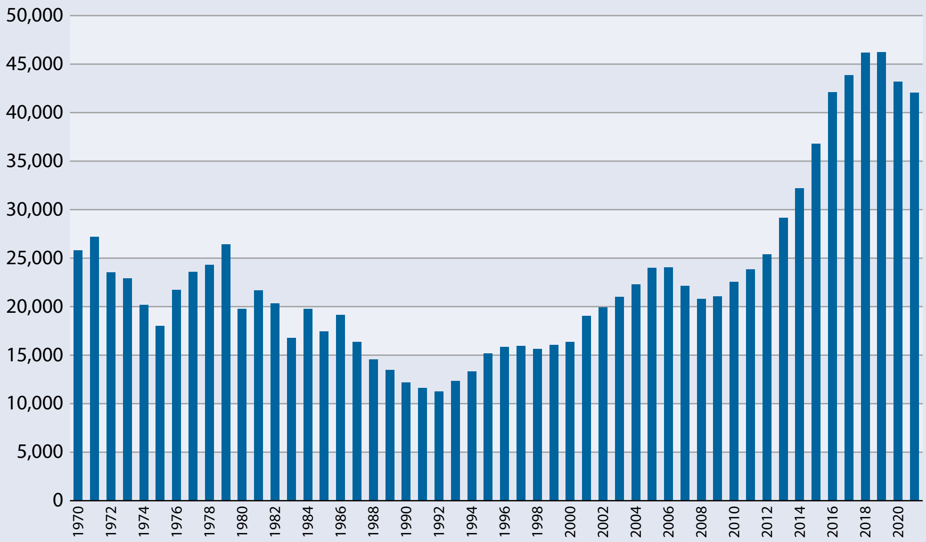


Source: Author's calculations based on the APO Productivity Database

- From 1970 to 2010, labor productivity generally showed a trend of repeated fluctuations, with the lowest point recorded in 1992. However, in the 2010s, there was a sharp increasing trend. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development. Nevertheless, in the 2020s, it is turning back to a decreasing trend.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



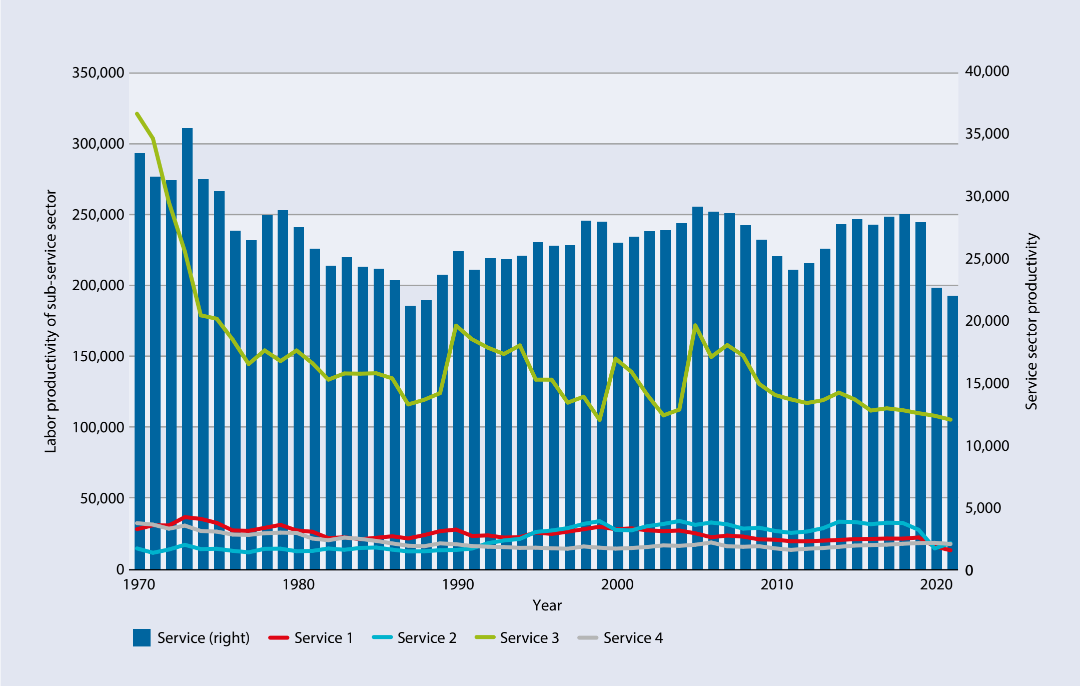
Source: Author's calculations based on the APO Productivity Database

<Service>

- Fiji's service sector productivity showed a gradual downward trend until 1990, after which it stabilized with minor fluctuations.

- Service Sector 3 (finance, real estate, renting, and business activities) demonstrated a strong start with high labor productivity, which declined and then stabilized at a lower level.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), have shown minimal change, maintaining their initial labor productivity levels over time.



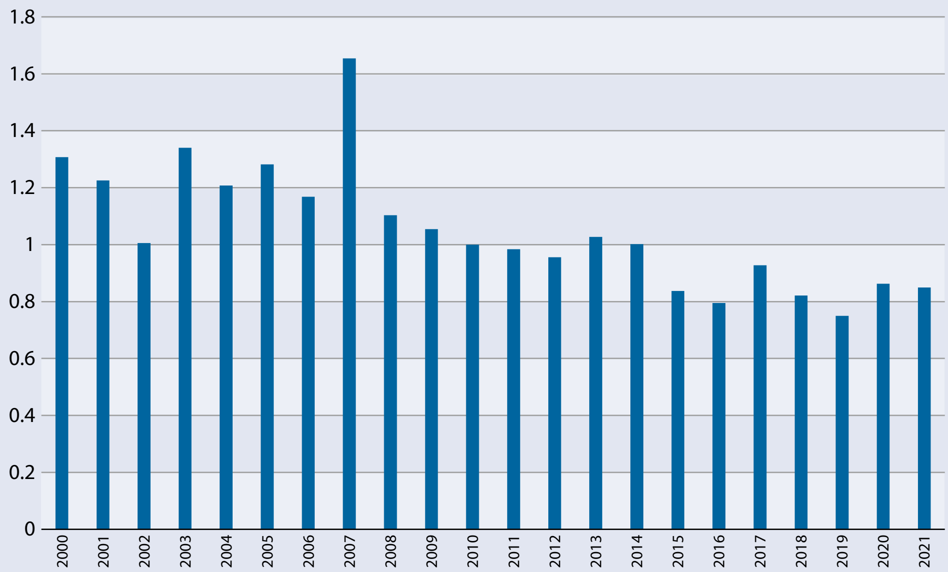
COUNTRY PROFILE: HONG KONG

<Agriculture>

- Agricultural labor productivity in Hong Kong experienced some fluctuations in the mid-2000s. Since then, it has shown a slight but consistent downward trend.

FIGURE 1

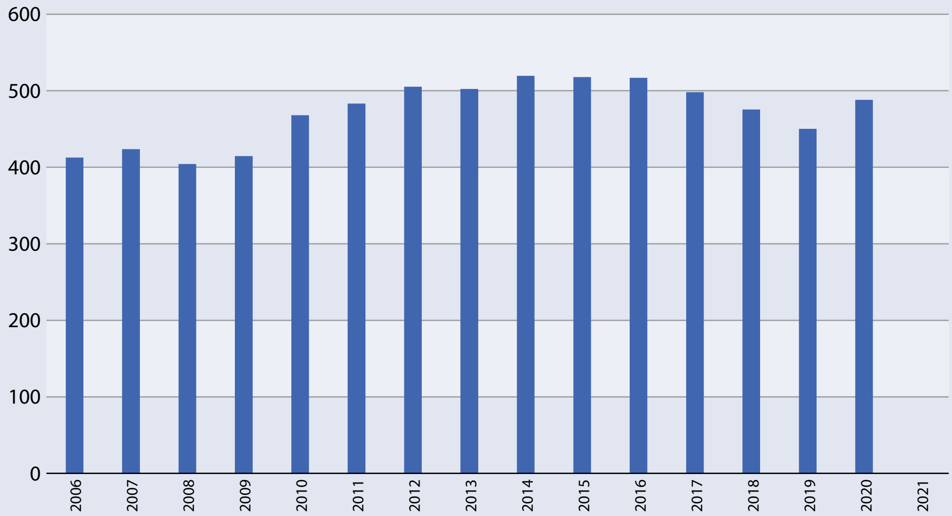
AGRICULTURAL LABOR PRODUCTIVITY



- In Hong Kong, fertilizer consumption has remained relatively stable, peaking around the late 2000s before slightly declining in recent years.

FIGURE 2

FERTILIZER CONSUMPTION

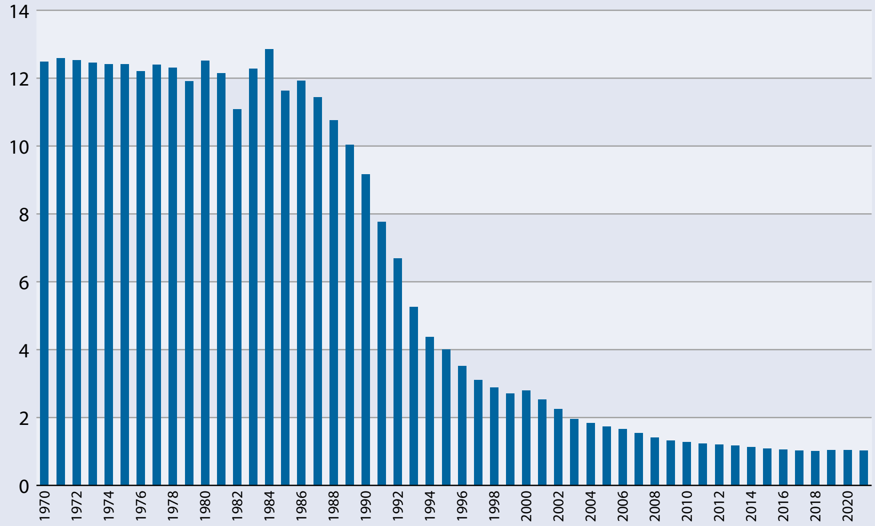


<Manufacturing>

- Manufacturing maintained around 12% in the 1970s and 1980s but showed a sharp decreasing trend after the 1990s, maintaining around 1% from the 2010s to the present. This seems to be a phenomenon that emerged as Hong Kong rose to become a hub of the global financial market starting in 1990.

FIGURE 3

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

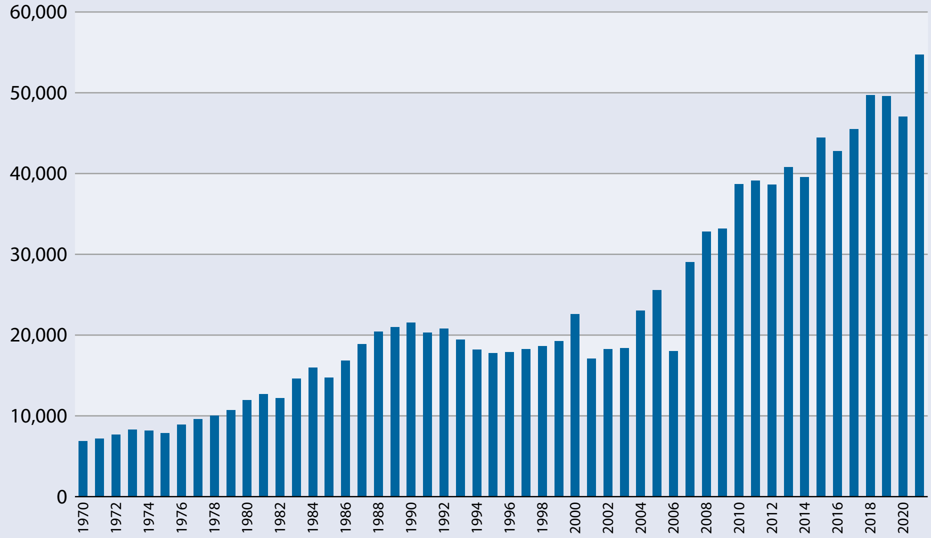


Source: Author's calculations based on the APO Productivity Database

- Although the share of manufacturing in GDP has decreased, labor productivity in manufacturing has continued to show an increasing trend. In particular, it increased sharply after 2008 and reached its highest level in 2021. This appears to be the result of the advancement of industrial structure based on the development of the financial industry, also manifesting in the manufacturing sector.

FIGURE 4

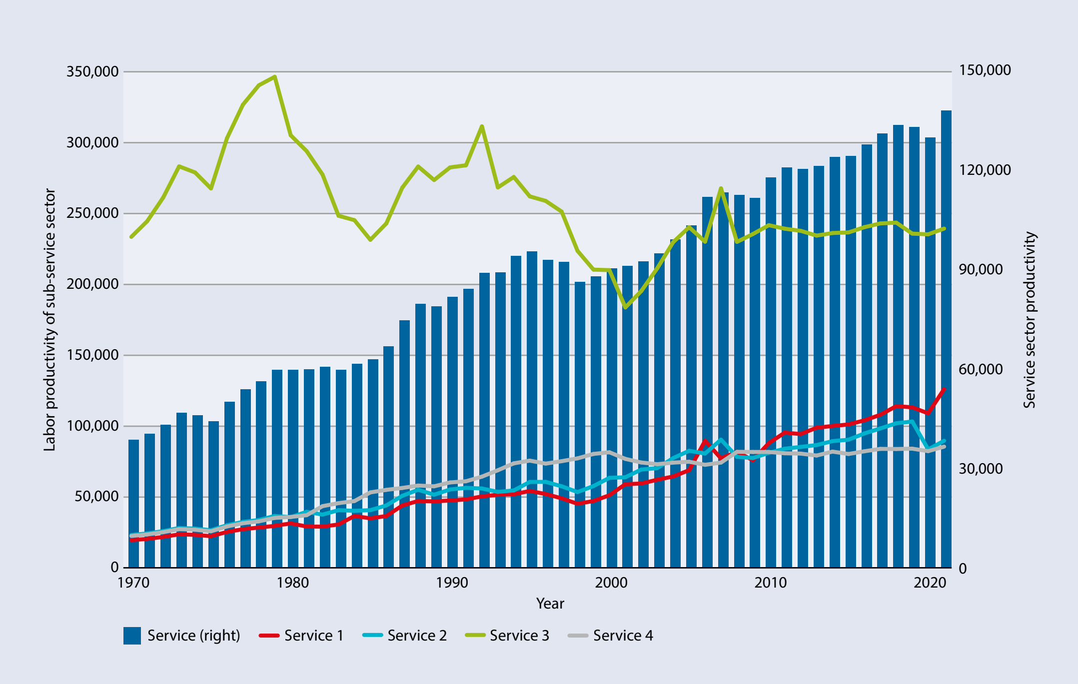
TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



Source: Author's calculations based on the APO Productivity Database

<Service>

- Hong Kong's service sector productivity began at a high level and continued a strong upward trajectory, eventually reaching approximately 150,000.
- Service Sector 3 (finance, real estate, renting, and business activities) initially exhibited high labor productivity, experienced fluctuations until the mid-2000s, and then maintained a stable level afterward.
- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), saw continuous improvements in labor productivity, highlighting a generally robust and growing service sector.



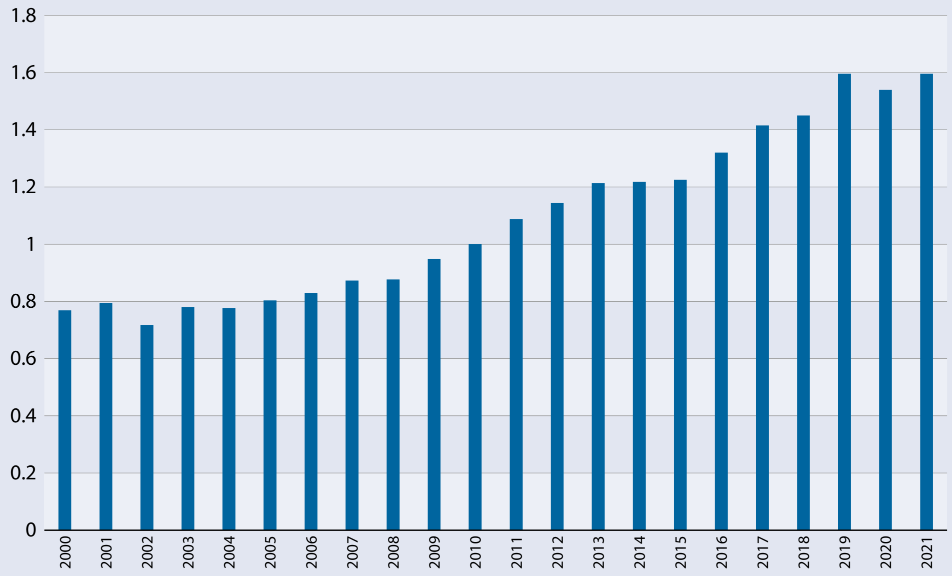
COUNTRY PROFILE: INDIA

<Agriculture>

- India's agricultural labor productivity has been on a consistent rise since the early 2000s. This growth trend continued robustly through 2021.

FIGURE 1

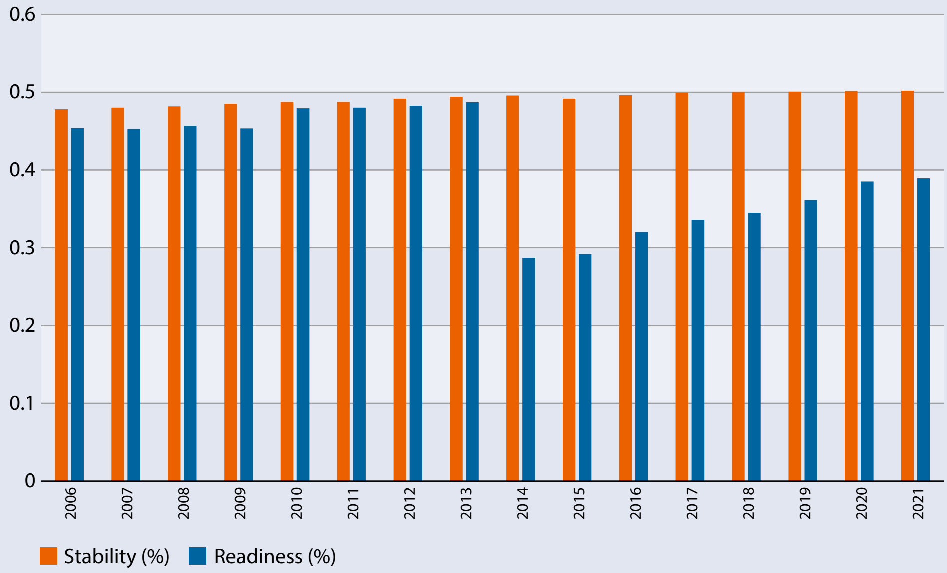
AGRICULTURAL LABOR PRODUCTIVITY



- India shows a consistent level of Stability, with Readiness slightly fluctuating. The overall trend reflects stable climate response variables.

FIGURE 2

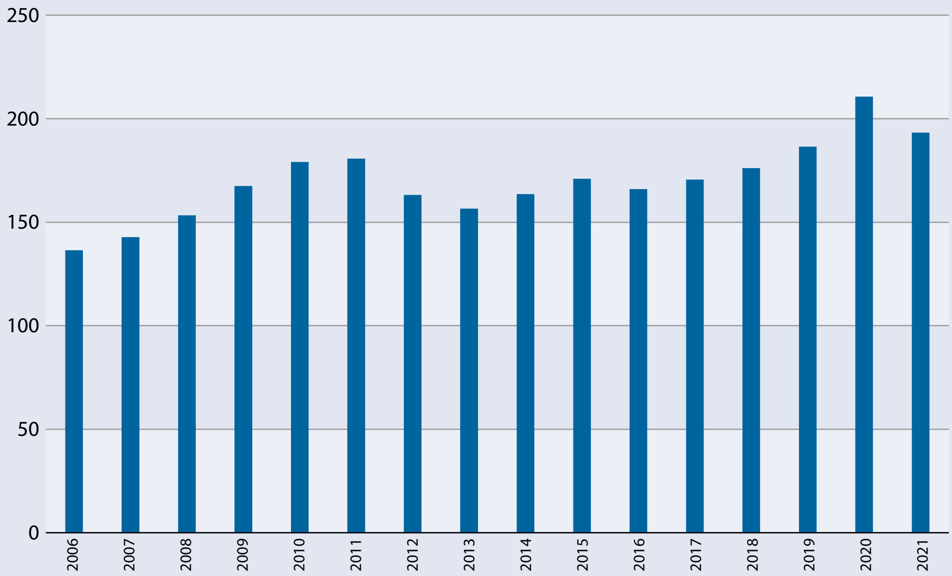
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Fertilizer use in India has steadily increased, with consistent growth in consumption over the years, particularly after 2010.

FIGURE 3

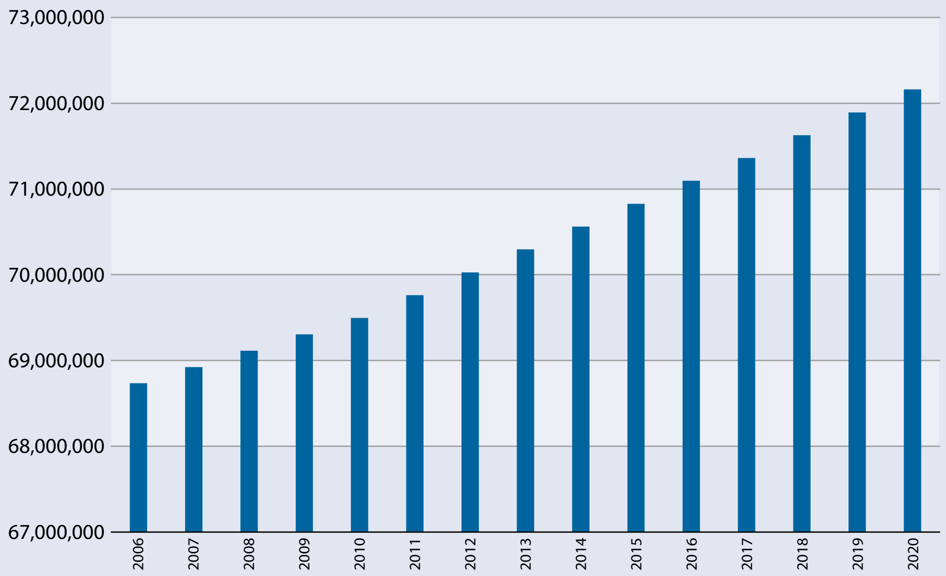
FERTILIZER CONSUMPTION



- India's forest area has shown a steady increase, with significant growth particularly after 2010.

FIGURE 4

FOREST AREA

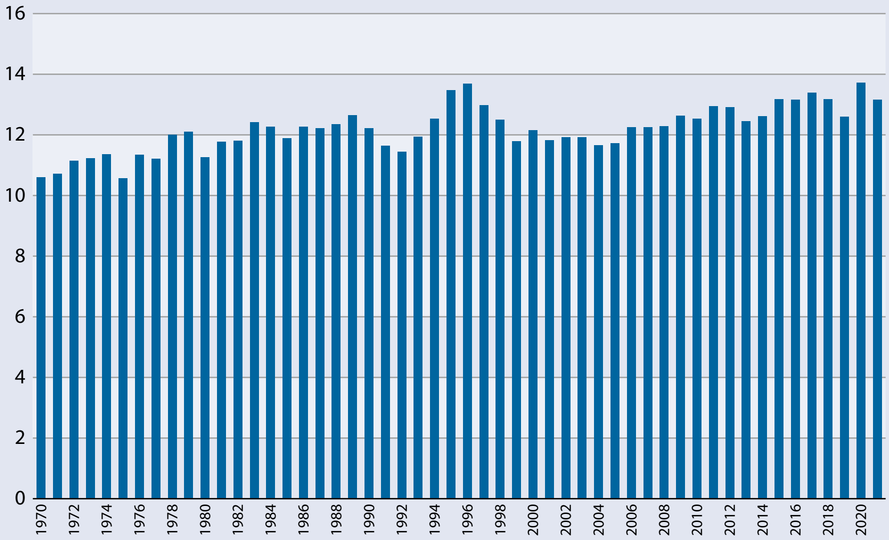


<Manufacturing>

- Although there is no large increase, it shows a steady increasing trend between 10% and 14%.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

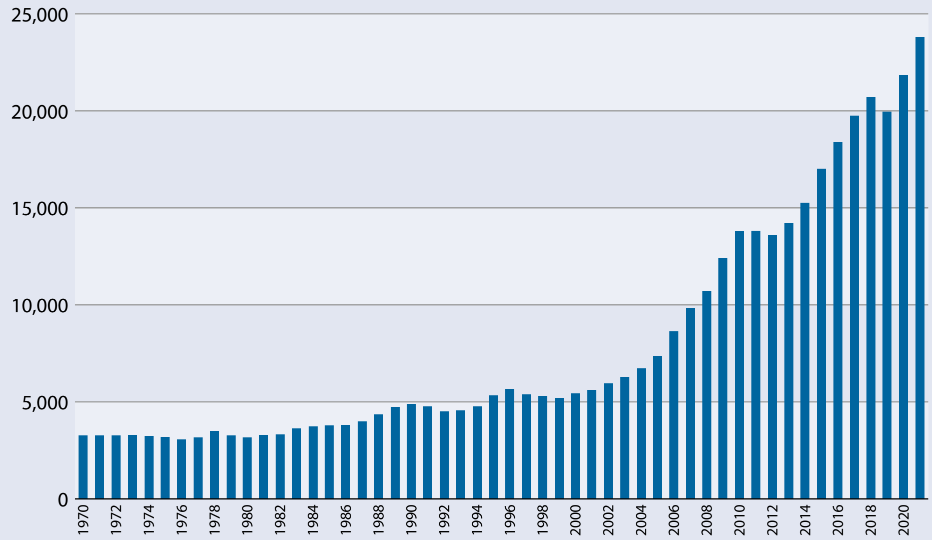


Source: Author's calculations based on the APO Productivity Database

- Unlike the relatively steady trend of the share of manufacturing in GDP, labor productivity has shown a significant increasing trend since the mid-2000s, reaching its highest point in 2021. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



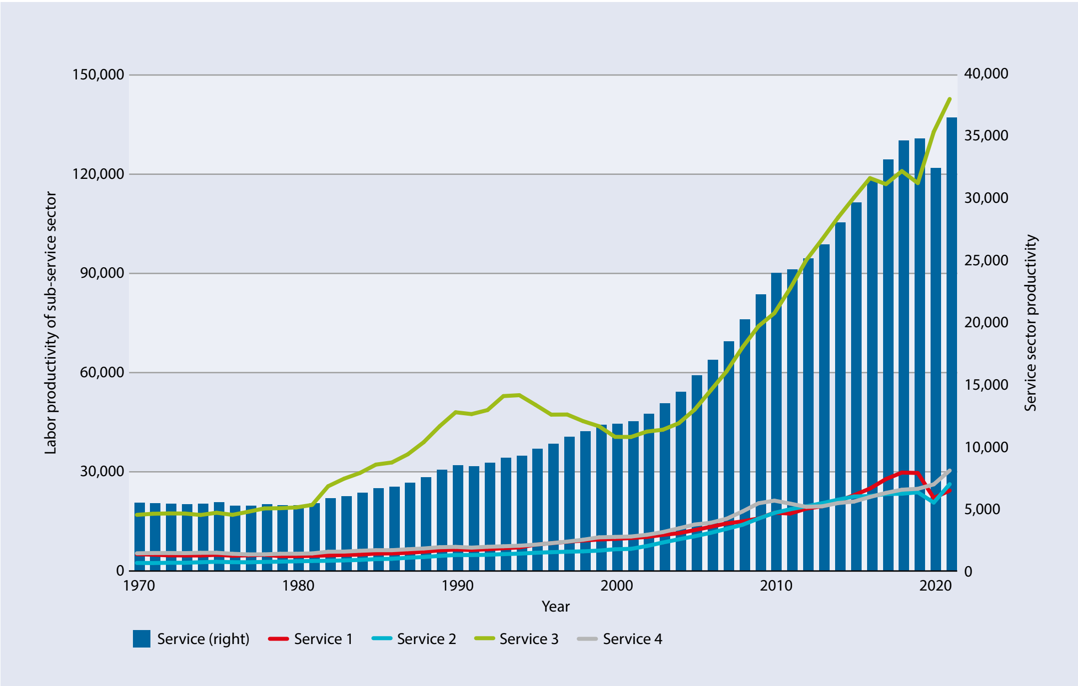
Source: Author's calculations based on the APO Productivity Database

<Service>

- India's service sector showed steady growth from the 1980s onward, with an especially marked acceleration in growth after 2000.

- The labor productivity of Service Sector 3 (finance, real estate, renting, and business activities) follows the general trend of overall service sector productivity, with a gradual increase up to 2000, followed by an accelerated rise thereafter.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), have experienced moderate growth in labor productivity, particularly over the past two decades, with productivity generally stable but showing a gradual upward trend.



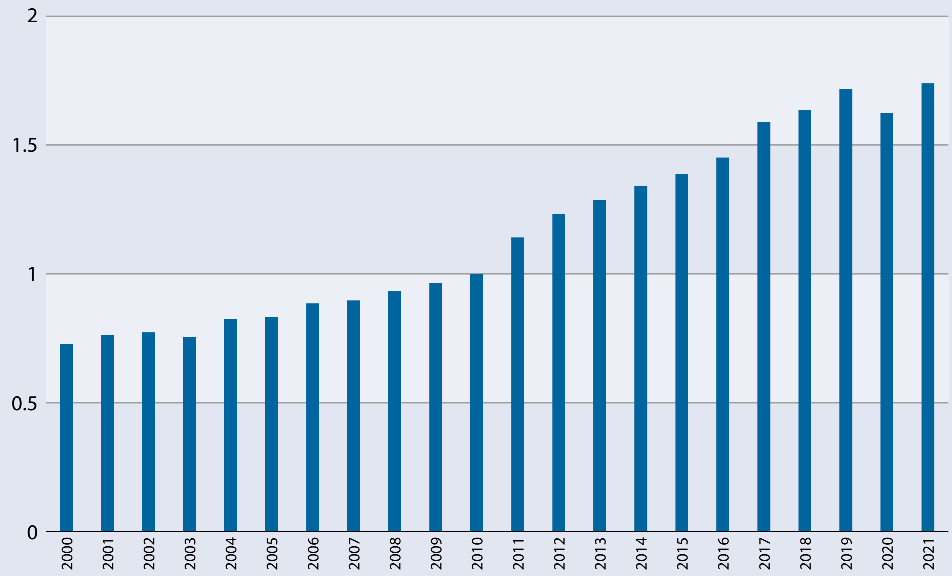
COUNTRY PROFILE: INDONESIA

<Agriculture>

- In Indonesia, there is a steady upward trend in agricultural labor productivity. A noticeable rise is observed particularly after 2016.

FIGURE 1

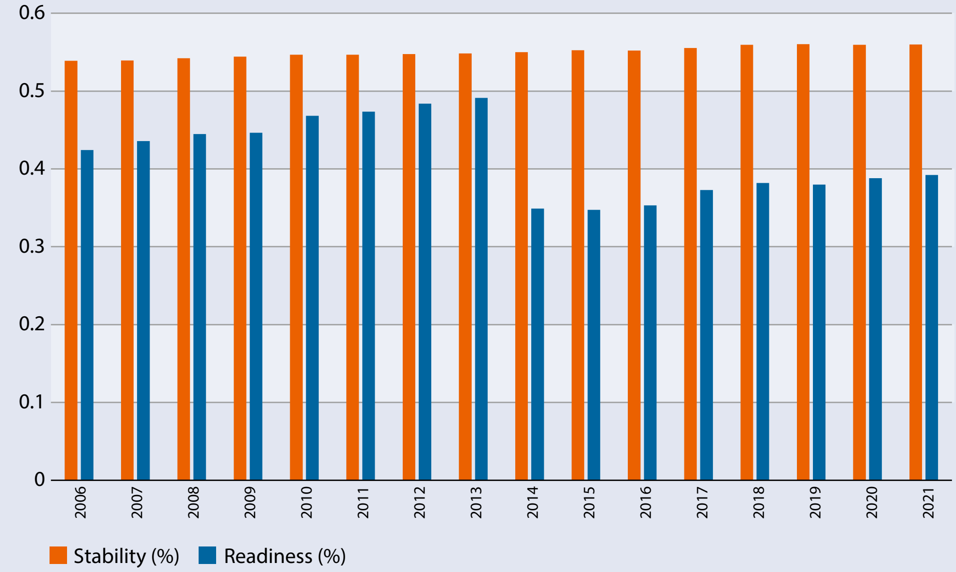
AGRICULTURAL LABOR PRODUCTIVITY



- Indonesia's Stability remains consistent over the years, while Readiness shows some minor fluctuations, indicating a moderate level of preparedness for climate change.

FIGURE 2

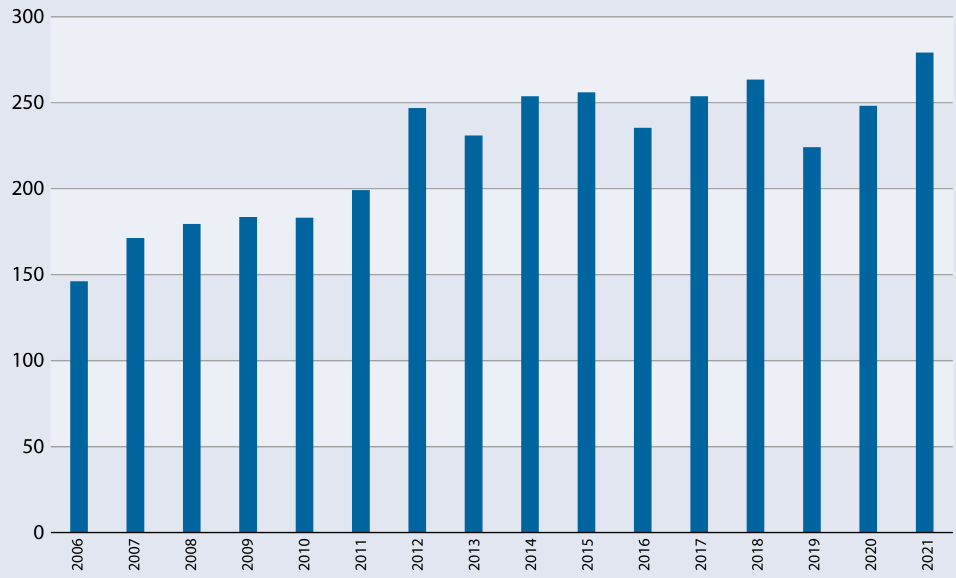
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Indonesia has shown a consistent increase in fertilizer consumption, with a steady upward trend particularly from the early 2000s onward.

FIGURE 3

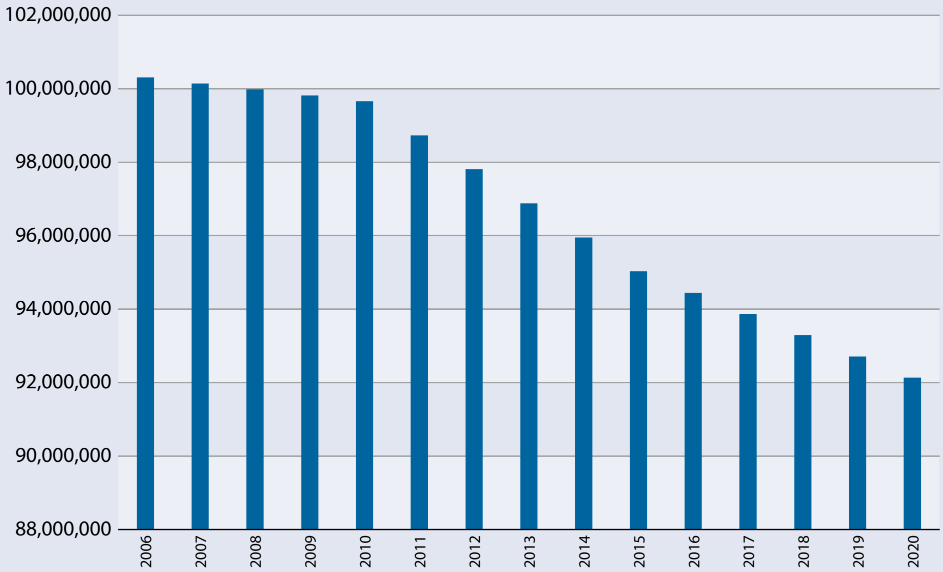
FERTILIZER CONSUMPTION



- Indonesia's forest area has steadily decreased over the years, indicating ongoing deforestation.

FIGURE 4

FOREST AREA

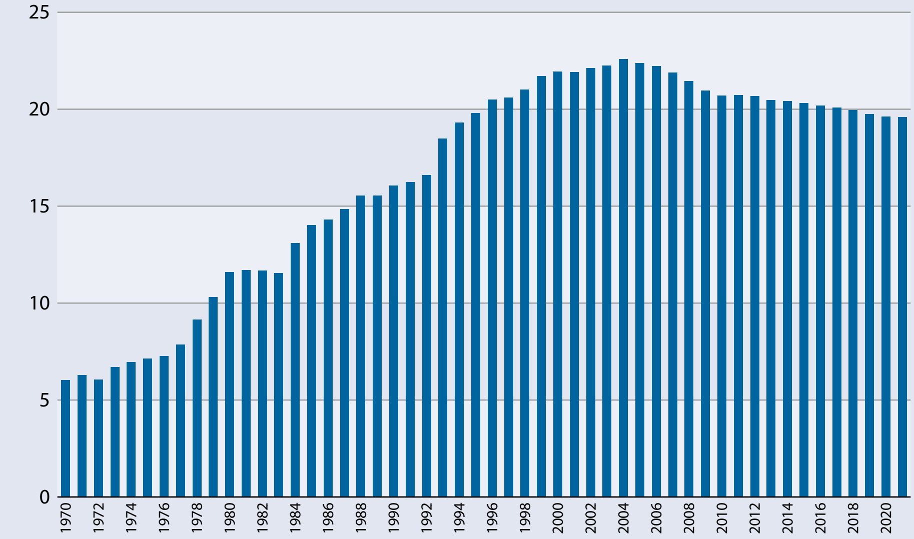


<Manufacturing>

- Manufacturing increased sharply and steadily from 1970, reaching its peak in 2004, but has been on a declining trend since then.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

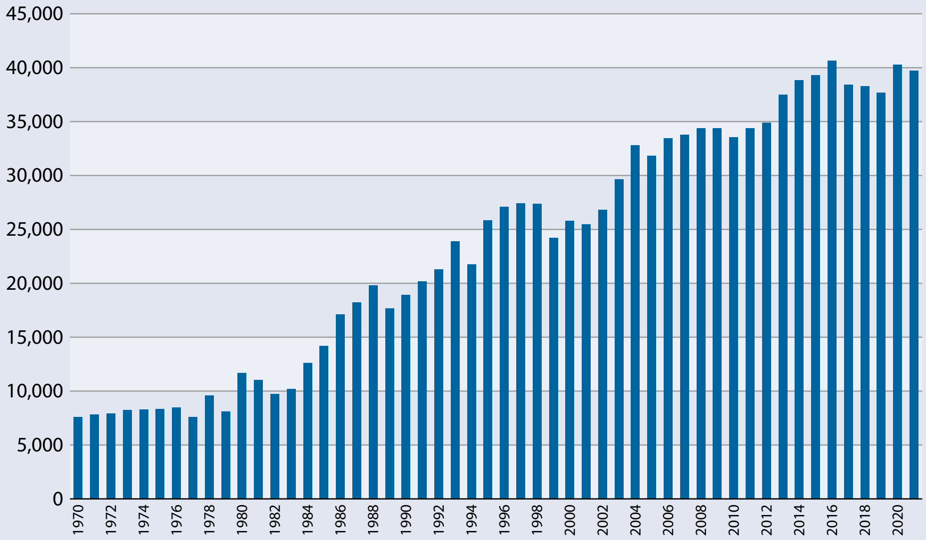


Source: Author's calculations based on the APO Productivity Database

- Unlike the trend of the declining share of manufacturing in GDP since 2004, labor productivity has shown a sharp and steady increasing trend since the 1980s. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



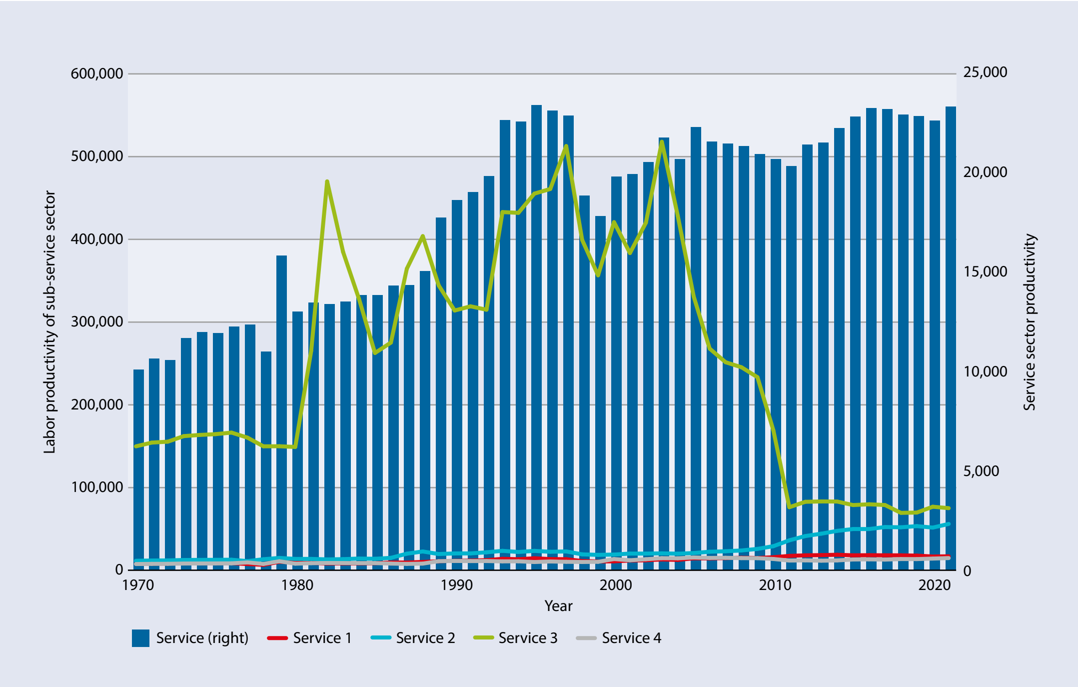
Source: Author's calculations based on the APO Productivity Database

<Service>

- Indonesia's service sector has shown substantial growth over the years, particularly in more recent decades, where productivity gains became more pronounced.

- Service Sector 3 (finance, real estate, renting, and business activities) initially experienced fluctuations in labor productivity, reaching a peak around 2000. However, it subsequently declined sharply, eventually stabilizing at a lower level in recent years.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), showed stable labor productivity over time, except for Service 2, which experienced a slight increase in recent years.



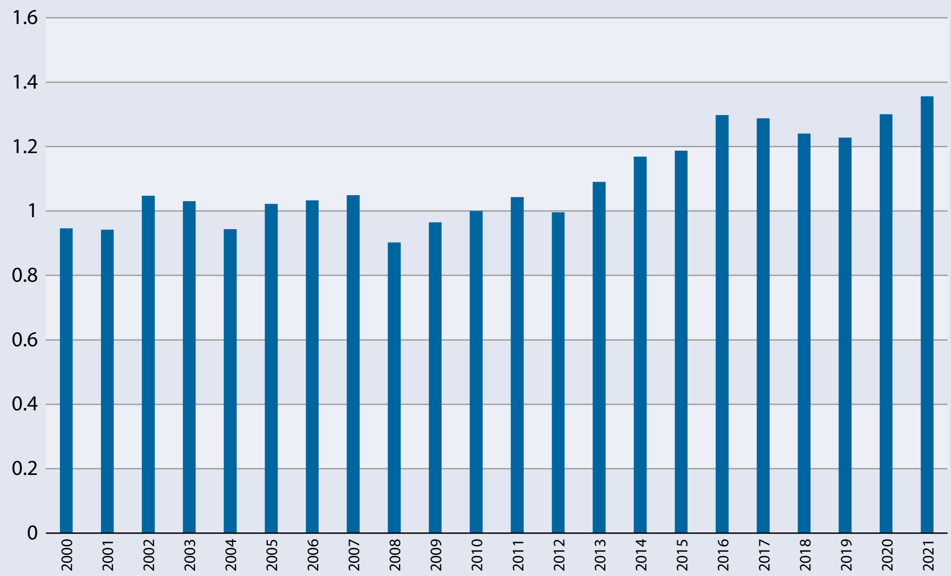
COUNTRY PROFILE: ISLAMIC REPUBLIC OF IRAN

<Agriculture>

- Islamic Republic of Iran (I.R. Iran) shows gradual growth in agricultural labor productivity, with stable improvement in recent years. This upward trajectory indicates enhanced efficiency in the sector.

FIGURE 1

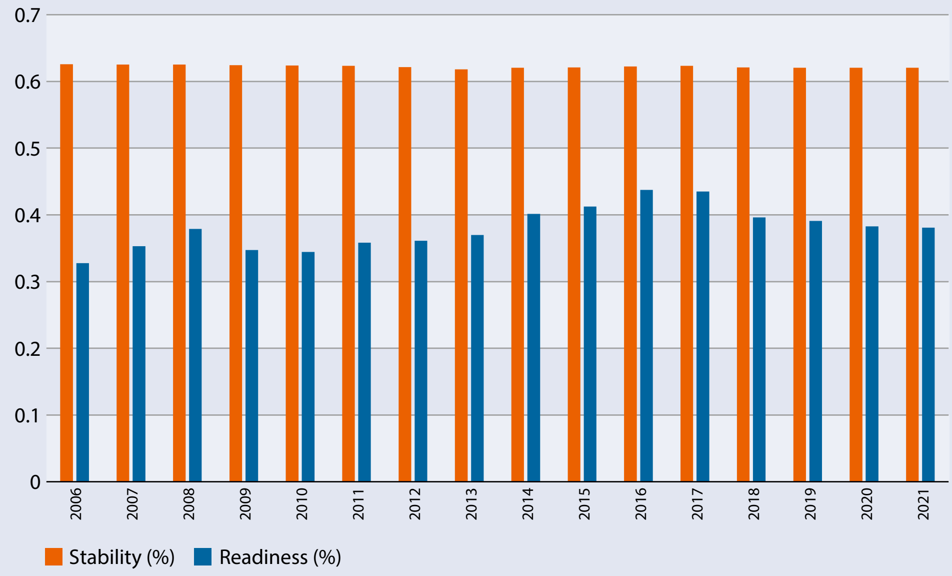
AGRICULTURAL LABOR PRODUCTIVITY



- I.R. Iran displays consistent Stability with small, steady improvements in Readiness over time, showing gradual enhancement in climate preparedness.

FIGURE 2

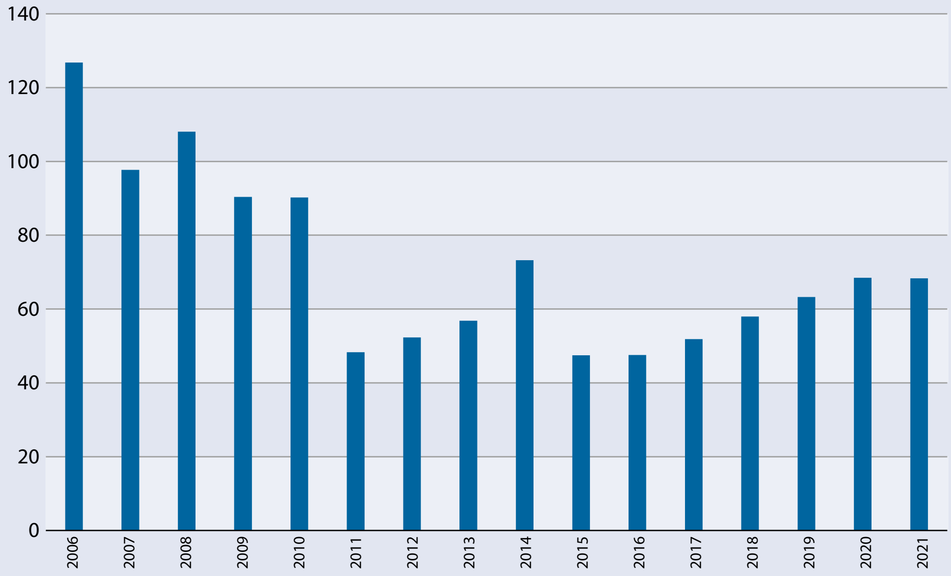
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- I.R. Iran displays a fluctuating trend in fertilizer consumption, with a moderate increase in recent years following a period of instability.

FIGURE 3

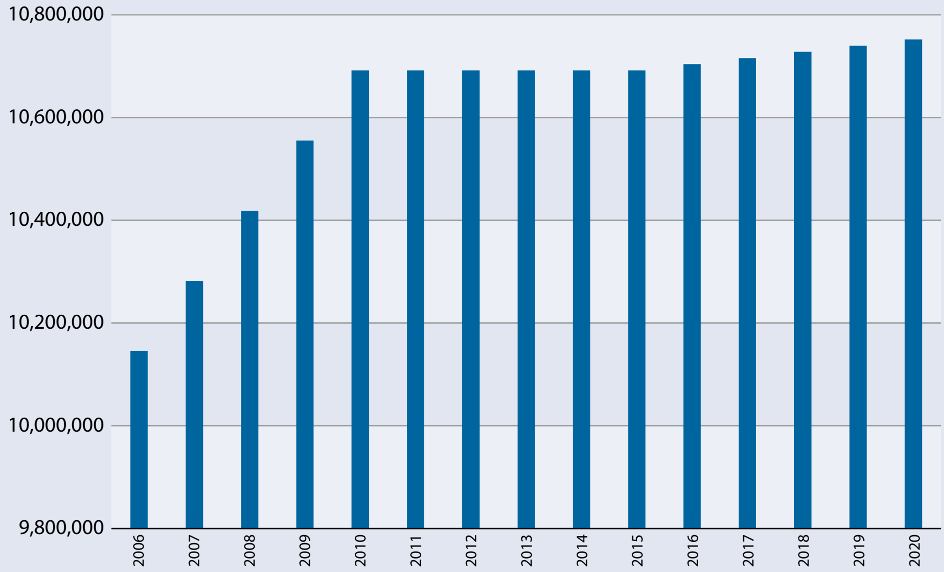
FERTILIZER CONSUMPTION



- I.R. Iran has seen a gradual increase in forest area, maintaining a consistent upward trend.

FIGURE 4

FOREST AREA

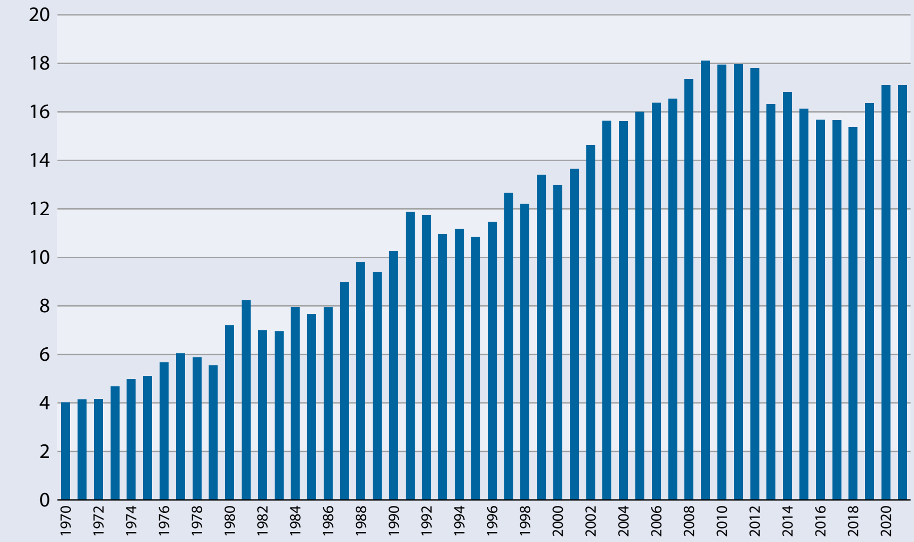


<Manufacturing>

- Manufacturing increased sharply and steadily from 1970, peaking in 2009, but has been on a declining trend since then. However, it has shown a rebound since 2019.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

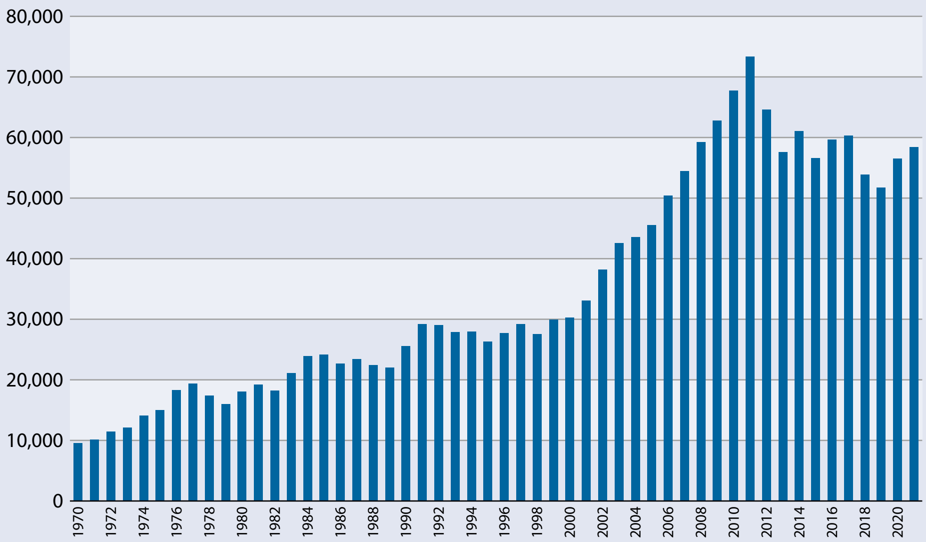


Source: Author's calculations based on the APO Productivity Database

- Labor productivity shows a trend very similar to the share of manufacturing in GDP. Particularly, it increased sharply in the 2000s. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development. However, it showed a sharp decline entering the 2010s.

FIGURE 6

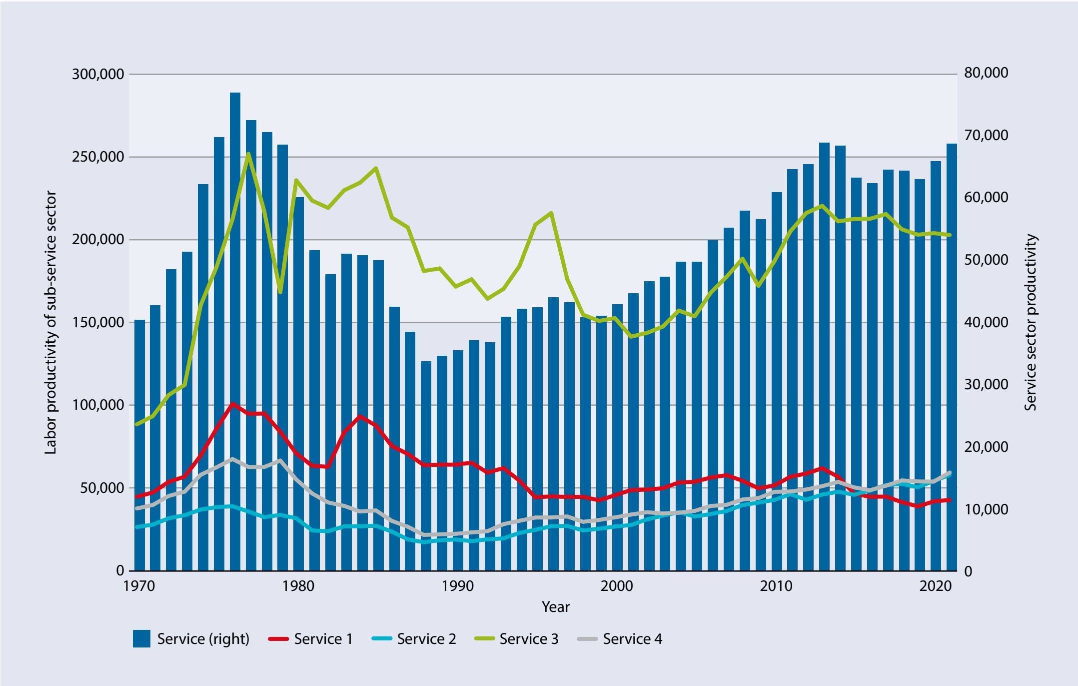
TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



Source: Author's calculations based on the APO Productivity Database

<Service>

- I.R. Iran's service sector productivity initially experienced fluctuations until the mid-1980s, after which it showed a steady increase over time.
- Service Sector 3 (finance, real estate, renting, and business activities) initially exhibited high labor productivity levels, which then fluctuated and settled at a relatively lower level compared to its early peak.
- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), exhibited fluctuating labor productivity until the mid-2000s, followed by a gradual upward trend in recent years.



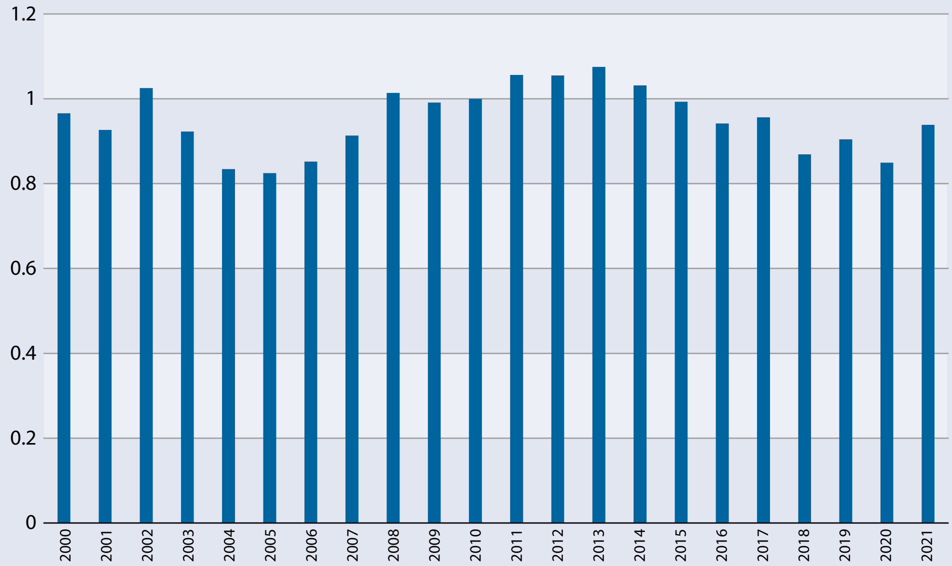
COUNTRY PROFILE: JAPAN

<Agriculture>

- Agricultural labor productivity in Japan has remained relatively stagnant over time. A slight decline has been observed since 2016.

FIGURE 1

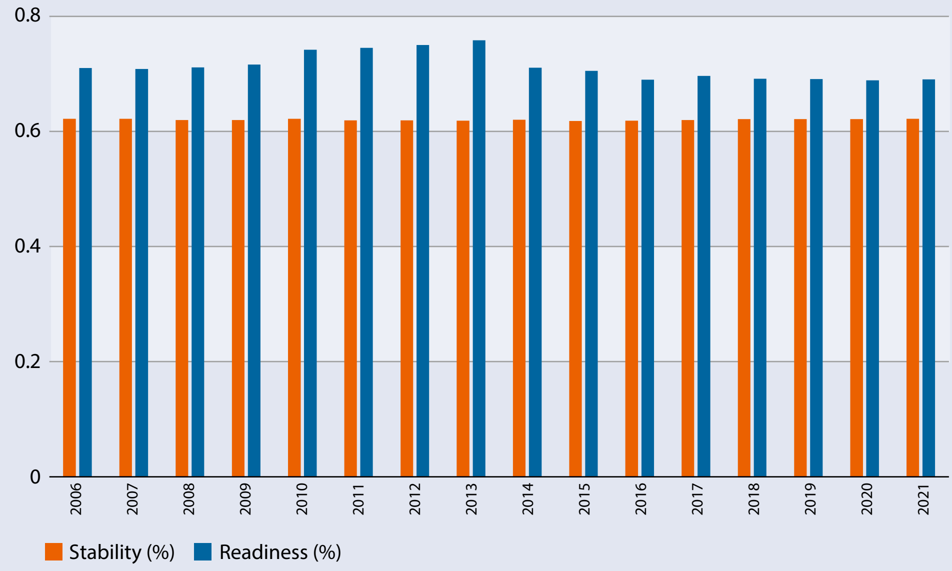
AGRICULTURAL LABOR PRODUCTIVITY



- In Japan, Stability is fairly constant, while Readiness fluctuates slightly but remains stable overall, indicating steady climate change response efforts.

FIGURE 2

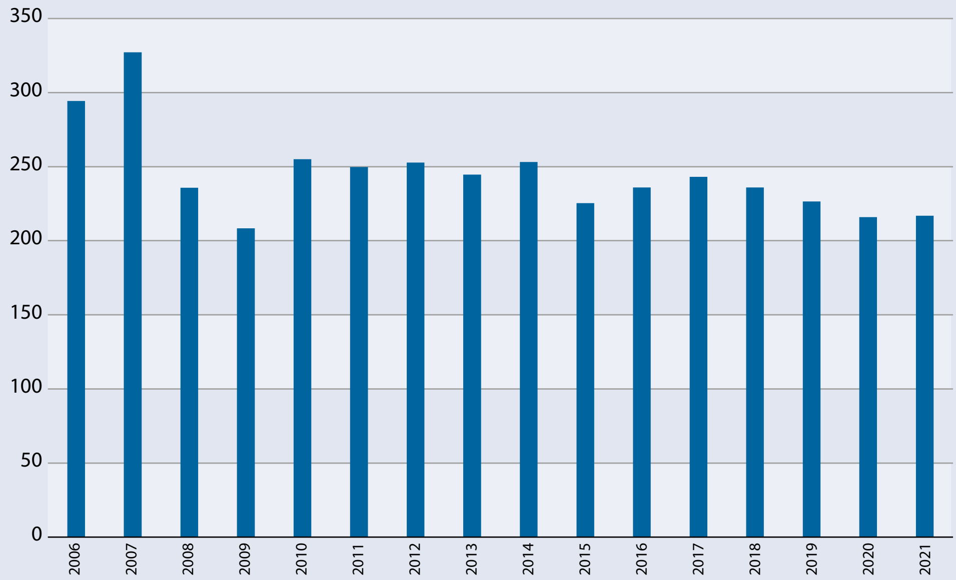
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Japan's fertilizer consumption is relatively stable, with minor fluctuations and no significant upward or downward trend.

FIGURE 3

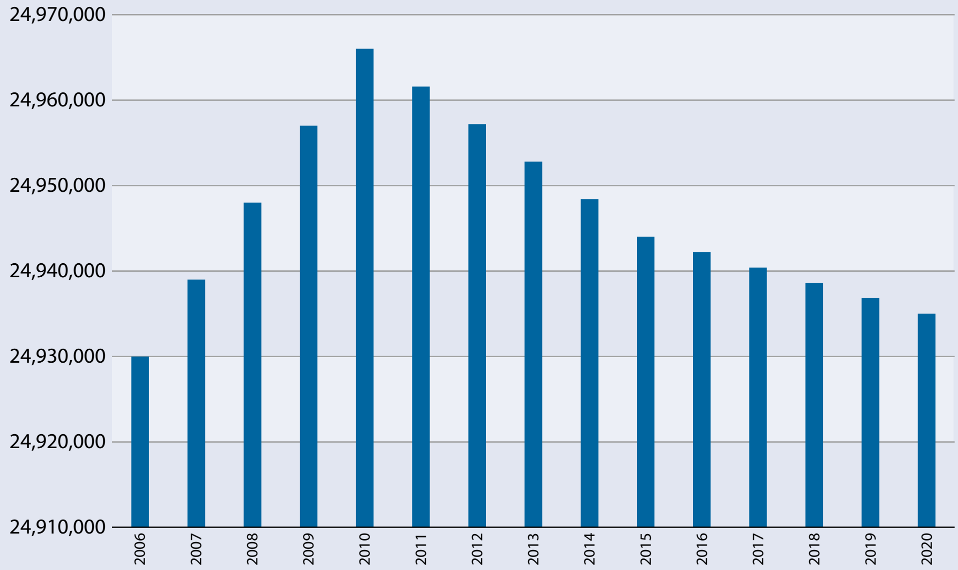
FERTILIZER CONSUMPTION



- Japan’s forest area remained relatively stable but has shown a slight decline in recent years.

FIGURE 4

FOREST AREA

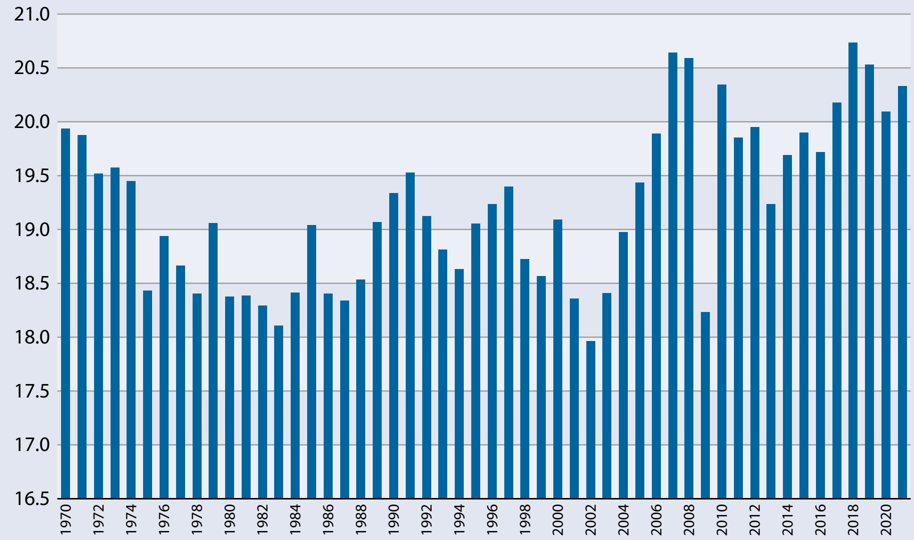


<Manufacturing>

- Unlike other countries, the year-to-year fluctuation is quite large. It increased sharply in the mid-2000s, then sharply decreased in the early 2010s, and recovered again in the late 2010s. It seems to be greatly influenced by global economic conditions, such as the global financial crisis.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

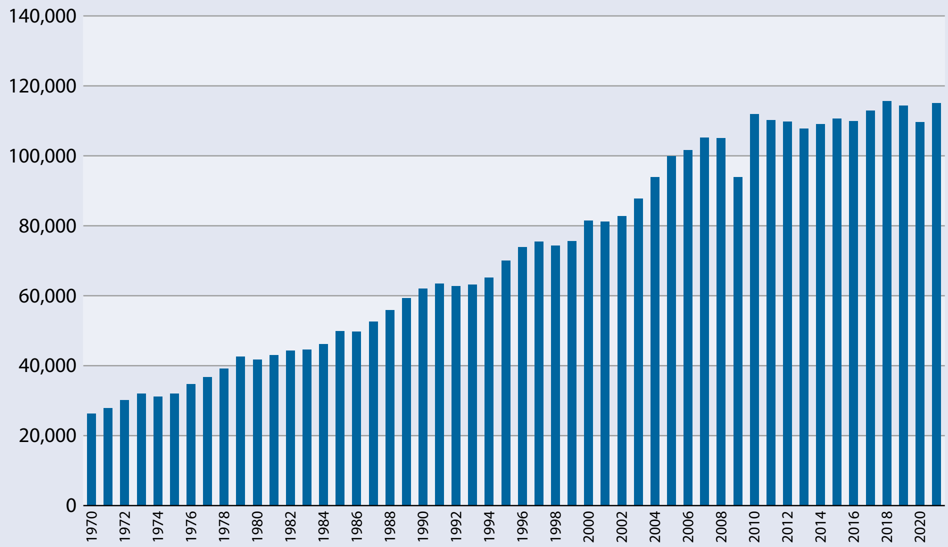


Source: Author's calculations based on the APO Productivity Database

- Unlike the trend of the manufacturing share in GDP, which has large fluctuations, labor productivity has shown a relatively steady increase since 1970. However, the significant decrease in 2009, when the global financial crisis occurred, suggests that it is greatly influenced by global economic fluctuations. Although it increased in the 2010s, the rate of increase was not as large as before.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



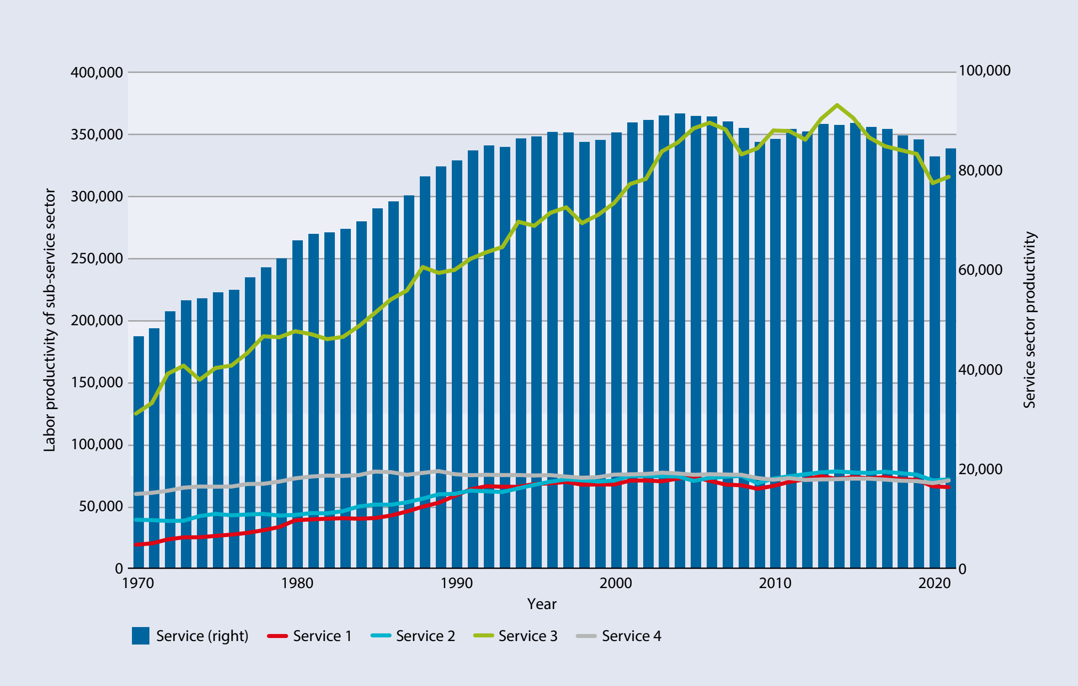
Source: Author's calculations based on the APO Productivity Database

<Service>

- Japan's service sector productivity initially began at a lower level, rose until the 1980s, and has since maintained a steady level.

- The labor productivity of Service Sector 3 (finance, real estate, renting, and business activities) follows a similar growth pattern to overall service productivity, increasing until the mid-2000s and then levelling off.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), experienced a slight increase in labor productivity in the early years, followed by minimal changes thereafter.



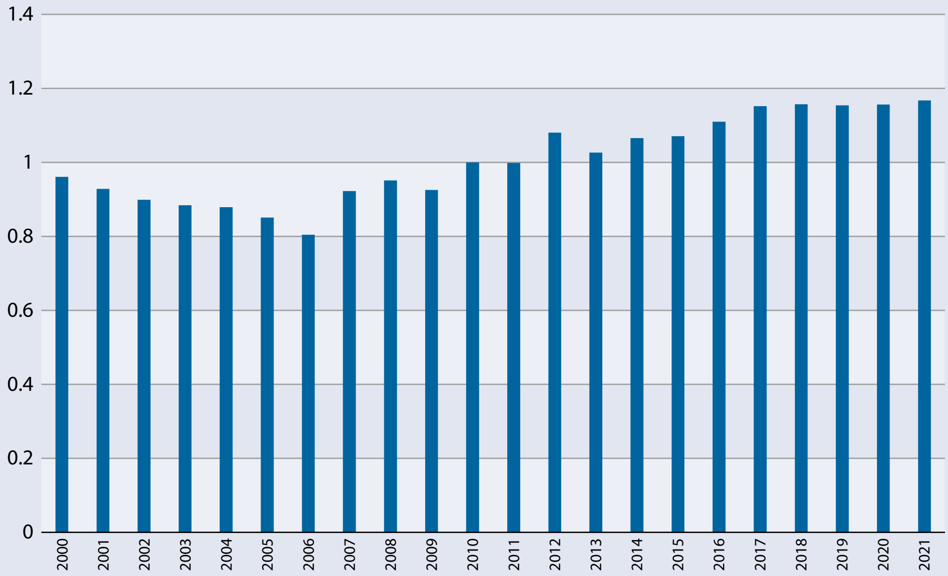
COUNTRY PROFILE: LAO PDR

<Agriculture>

- Lao PDR has seen consistent growth in agricultural labor productivity since the 2000s. Recent years reflect steady gains in this sector.

FIGURE 1

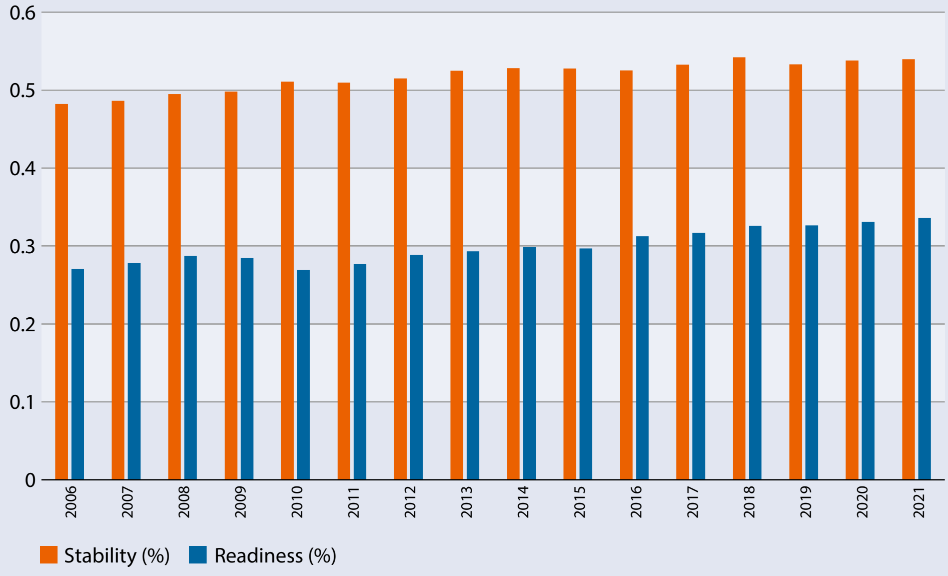
AGRICULTURAL LABOR PRODUCTIVITY



- Lao PDR maintains consistent Stability levels, with Readiness slightly fluctuating over the years but generally remaining stable.

FIGURE 2

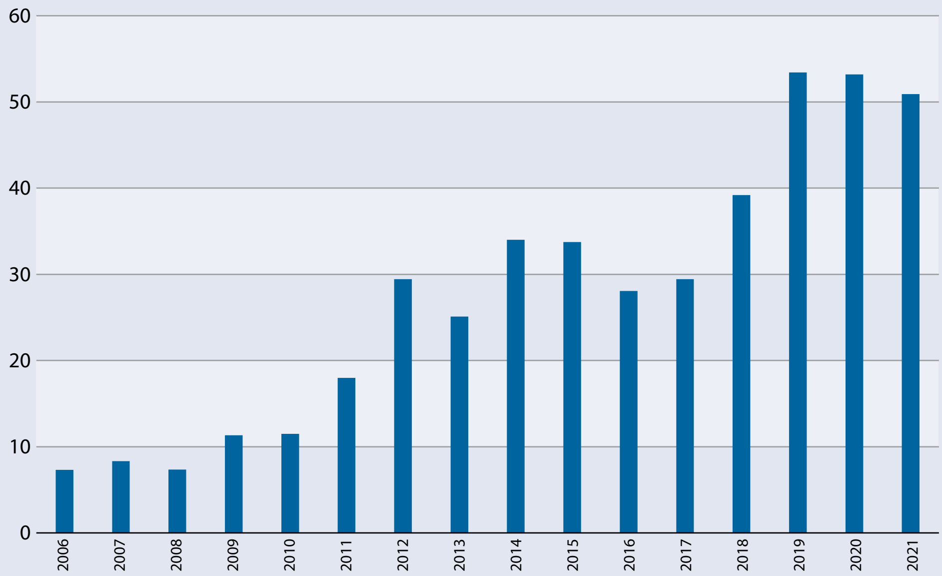
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Lao PDR has experienced a rapid rise in fertilizer consumption, especially noticeable from 2010 onwards, indicating growing agricultural intensification.

FIGURE 3

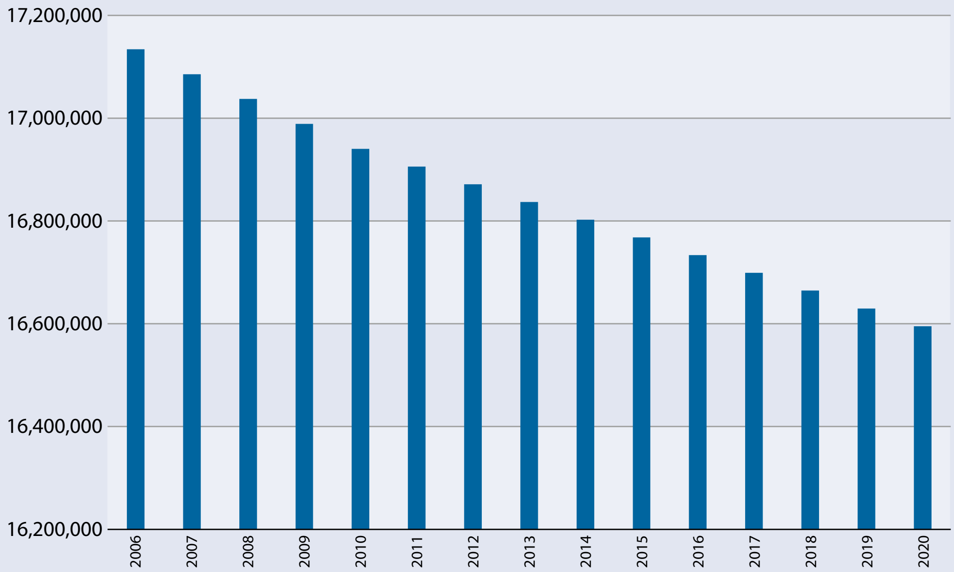
FERTILIZER CONSUMPTION



- Lao PDR has experienced a steady decline in forest area over the years, reflecting ongoing deforestation.

FIGURE 4

FOREST AREA

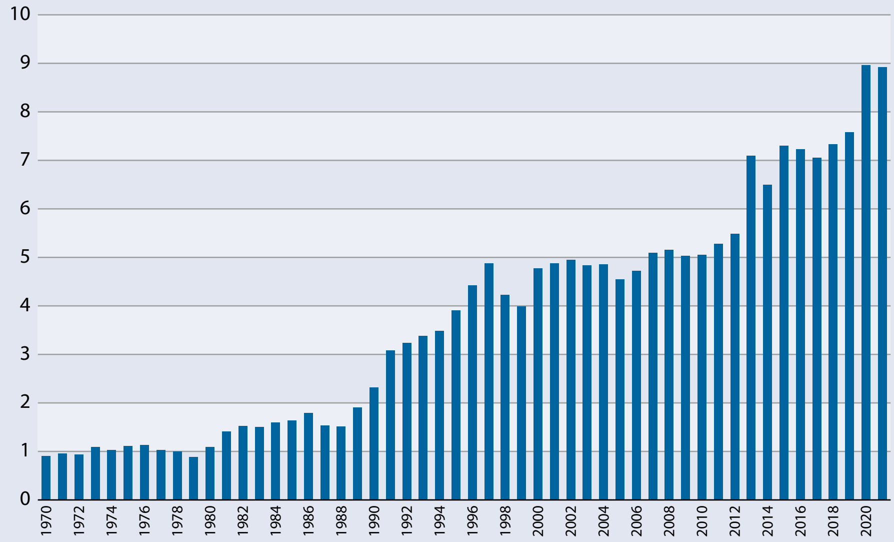


<Manufacturing>

- Manufacturing has been showing a steadily increasing trend. In particular, it increased sharply in the mid to late 1990s, the early to mid-2010s, and the early 2020s.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

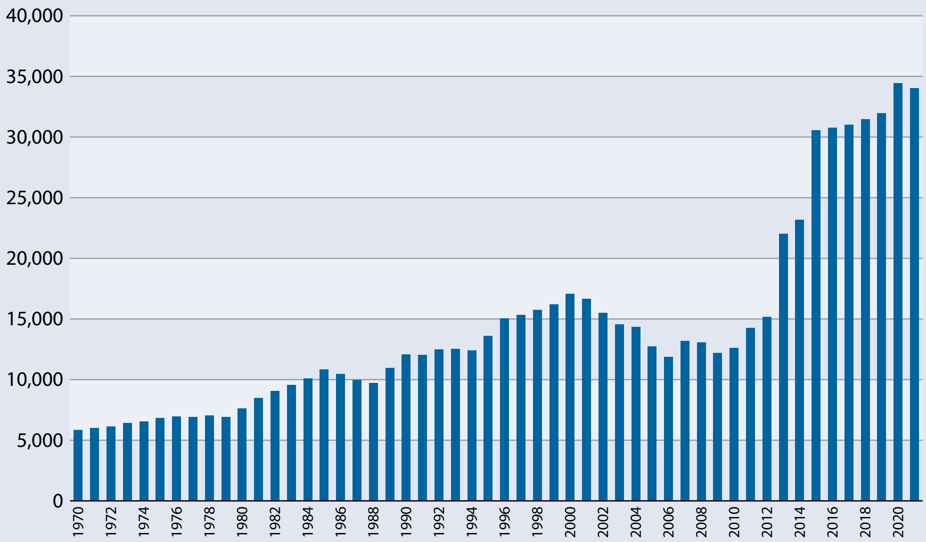


Source: Author's calculations based on the APO Productivity Database

- Labor productivity has shown a steadily increasing trend since 1970, and has increased significantly, especially in the 2010s. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



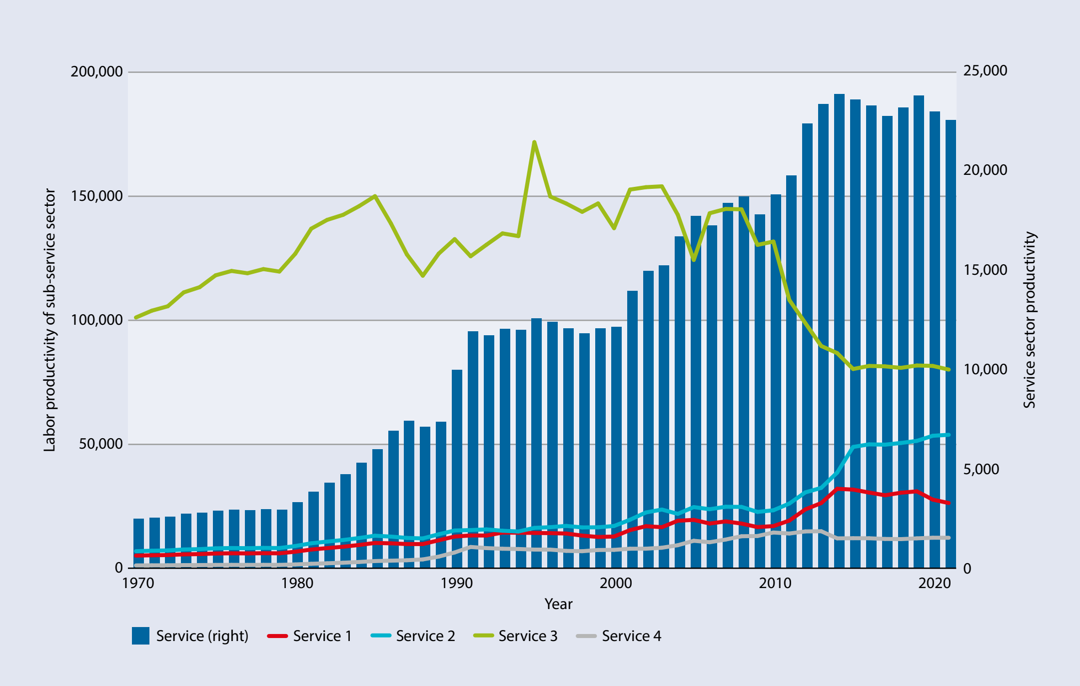
Source: Author's calculations based on the APO Productivity Database

<Service>

- Lao PDR's service sector productivity has steadily increased since the 1970s, starting below 5,000 and reaching above 20,000 by 2020, showing a strong upward trend.

- Service Sector 3 (finance, real estate, renting, and business activities) initially demonstrated high volatility, with labor productivity peaking around 150,000 in the late 1990s before stabilizing at a lower level near 100,000 by 2020.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), started with very low labor productivity levels but have demonstrated a gradual growth trend in recent years.



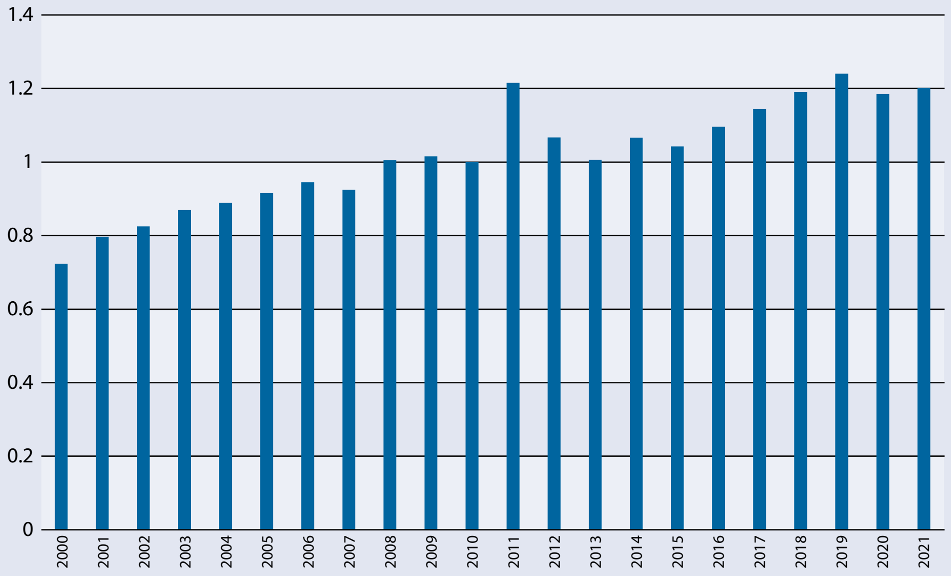
COUNTRY PROFILE: MALAYSIA

<Agriculture>

- Malaysia demonstrates an overall upward trend in agricultural labor productivity. Nevertheless, some fluctuations have been observed over the years.

FIGURE 1

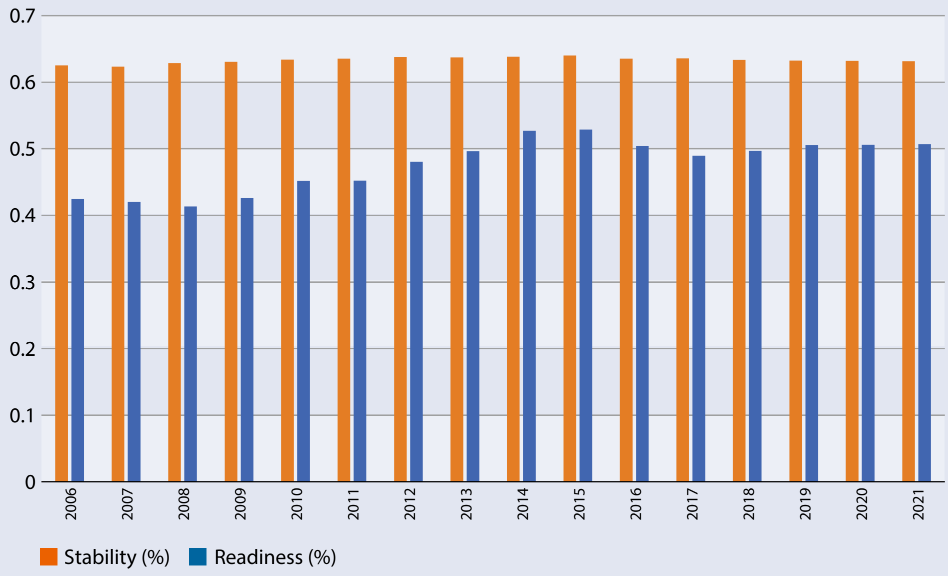
AGRICULTURAL LABOR PRODUCTIVITY



- Malaysia's Stability remains constant, with Readiness fluctuating slightly, maintaining steady climate change response efforts.

FIGURE 2

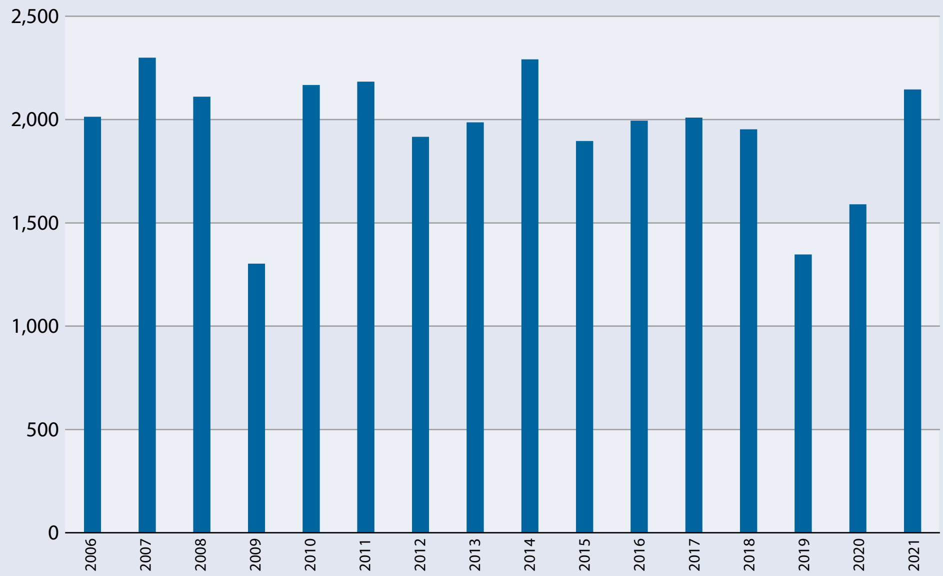
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Fertilizer use in Malaysia fluctuates over time, showing peaks and troughs without a clear long-term trend.

FIGURE 3

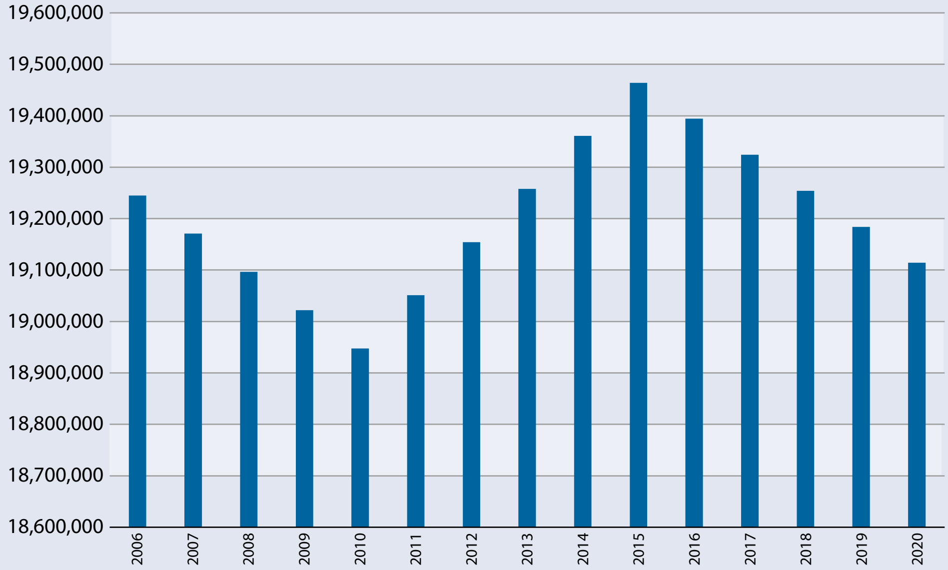
FERTILIZER CONSUMPTION



- Malaysia's forest area shows fluctuations, with a general decline followed by periods of recovery.

FIGURE 4

FOREST AREA

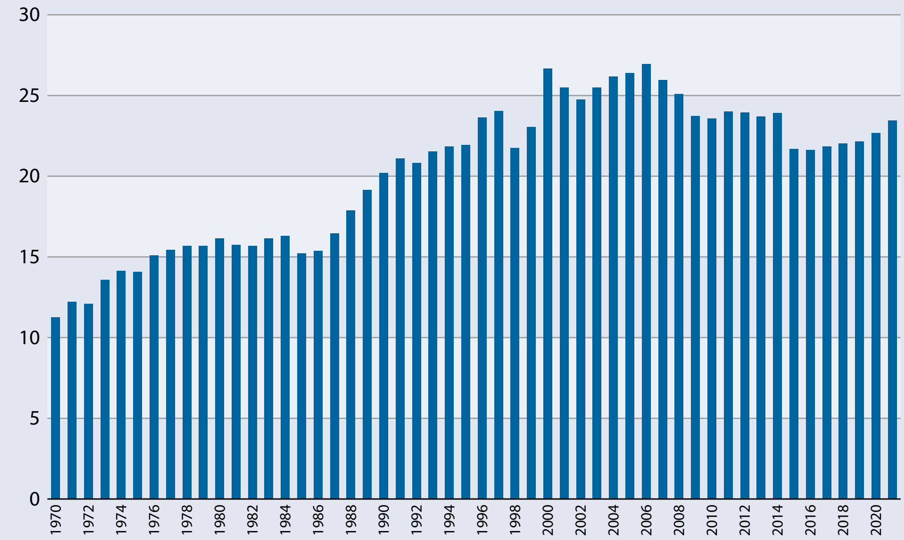


<Manufacturing>

- Manufacturing has steadily increased since 1970, reaching its peak in 2001, but has been somewhat declining since then. However, it shows a rebound trend entering the 2020s.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

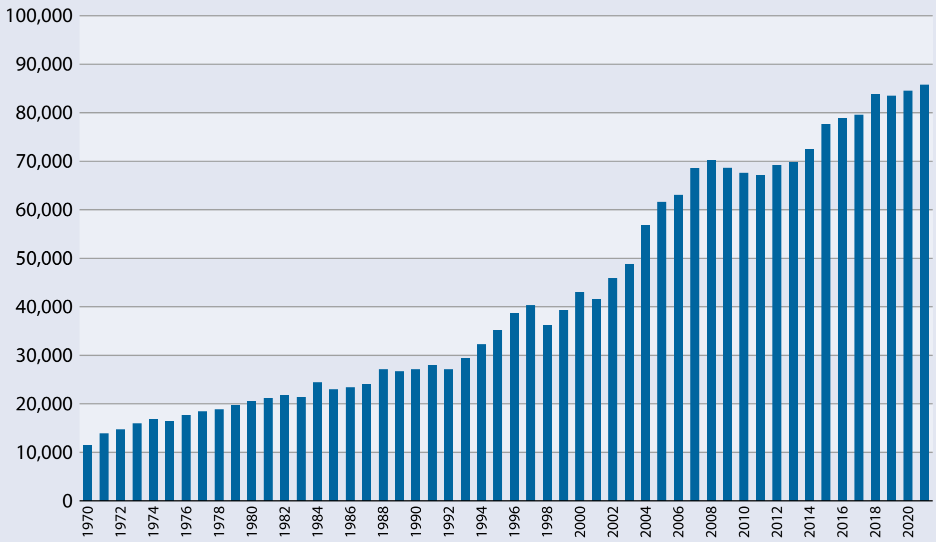


Source: Author's calculations based on the APO Productivity Database

- Labor productivity shows an upward trend, reflecting improvements in efficiency and potential technological adoption. It increased significantly, especially from the mid-2000s, and reached its highest level in 2021.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



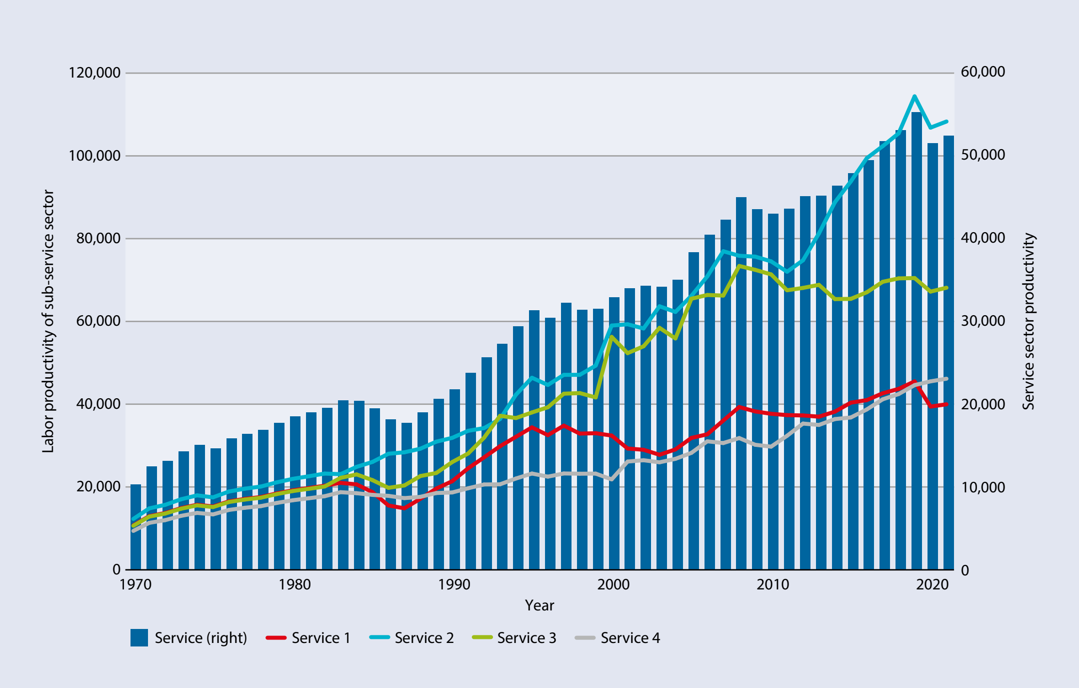
Source: Author's calculations based on the APO Productivity Database

<Service>

- Malaysia's service sector productivity shows a continuous growth trajectory, beginning around 10,000 in the early 1970s and climbing to over 50,000 by 2020.

- Service Sector 3 (finance, real estate, renting, and business activities) shows lower labor productivity levels than Service Sector 2, which contrasts with patterns observed in other countries. Labor productivity in Service Sector 3 increased until the mid-2000s and then stabilized.

- Service Sector 2 (transport and communications) has consistently shown the highest labor productivity levels among the service sectors throughout the period, with a gradual upward trend. Service 1 (wholesale and retail trade) and Service 4 (community and personal services) have exhibited steady growth, reaching around 50,000 by 2020.



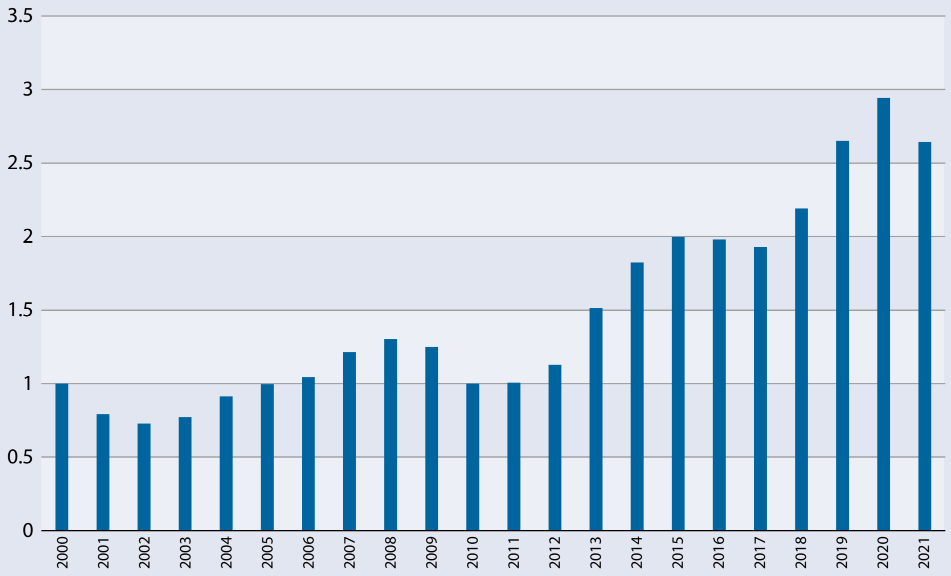
COUNTRY PROFILE: MONGOLIA

<Agriculture>

- In Mongolia, agricultural labor productivity has shown steady growth since the mid-2000s. This trend of improvement continued through 2021.

FIGURE 1

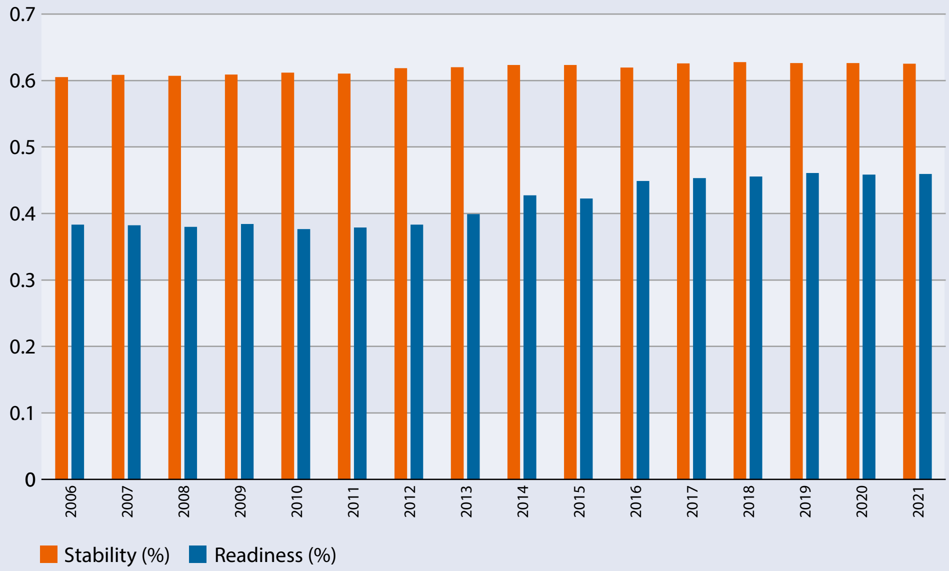
AGRICULTURAL LABOR PRODUCTIVITY



- Mongolia shows consistent Stability, with Readiness exhibiting gradual growth over time, reflecting increased climate adaptation efforts.

FIGURE 2

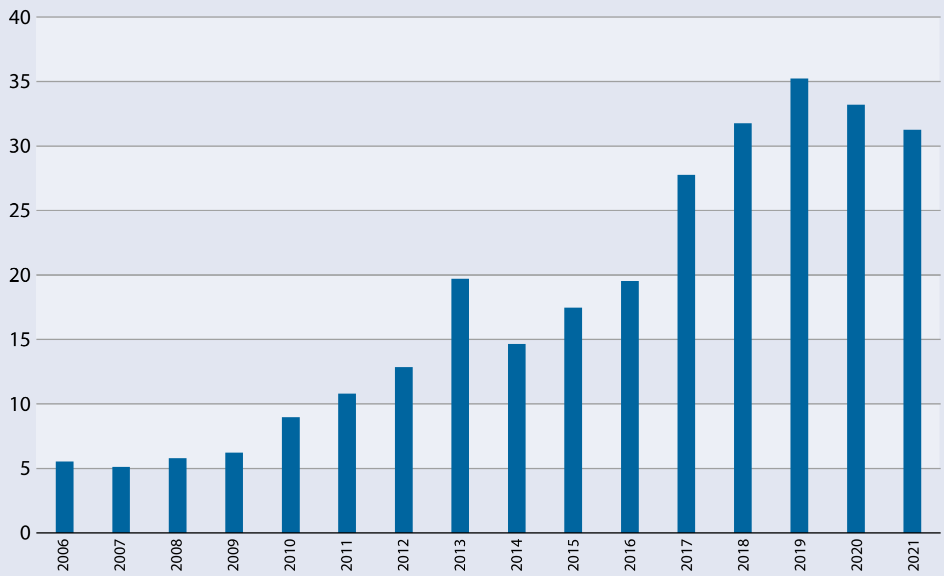
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Mongolia's fertilizer consumption has increased significantly over the years, showing a clear upward trend, especially after 2010.

FIGURE 3

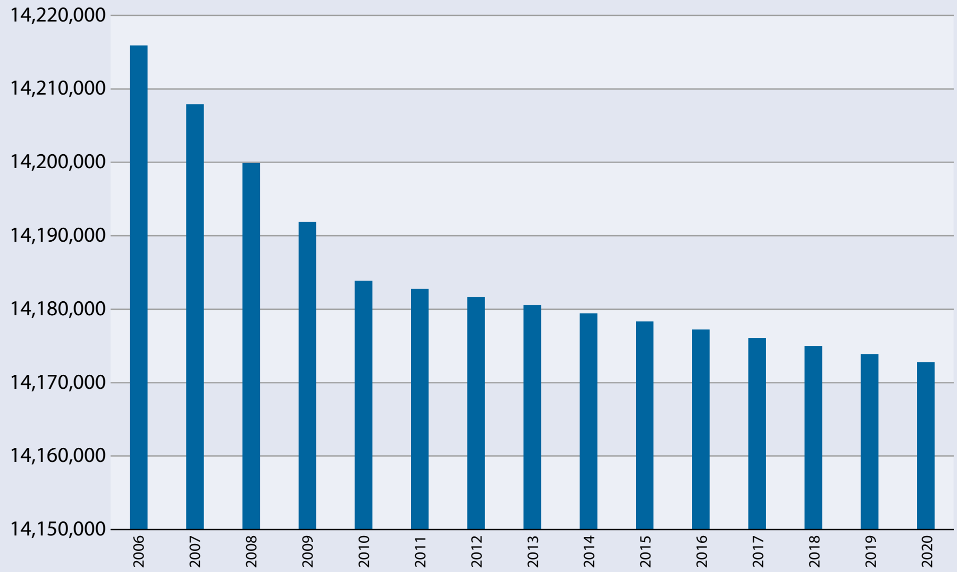
FERTILIZER CONSUMPTION



- Mongolia's forest area has steadily decreased, with a consistent downward trend over the period.

FIGURE 4

FOREST AREA

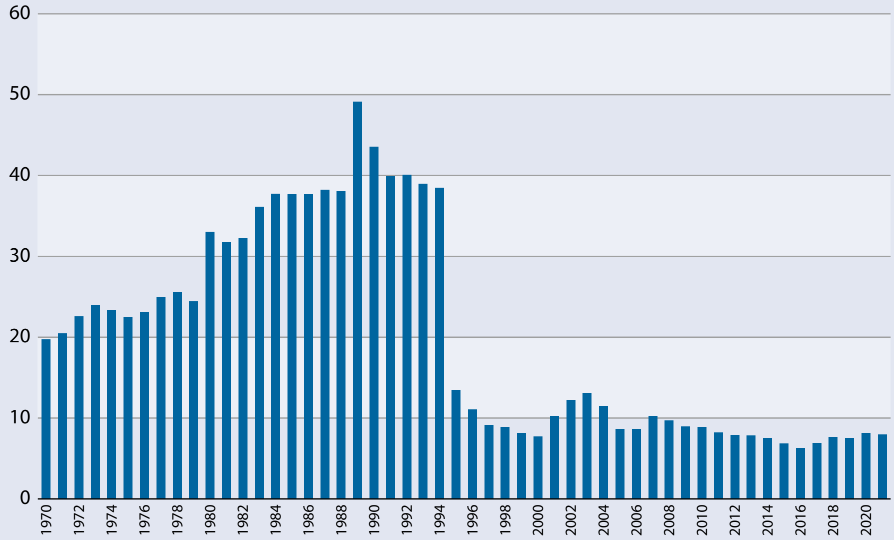


<Manufacturing>

- Manufacturing showed a relative increasing trend from 1970 to the 1980s. The manufacturing share in GDP may be relatively stable or slowly increasing, suggesting gradual industrial development. However, it turned into a declining trend afterward, and in particular dropped sharply in 1995. Since then, although it has shown some fluctuations, it has been on a declining trend at a level below 10% from the 2010s to the present.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

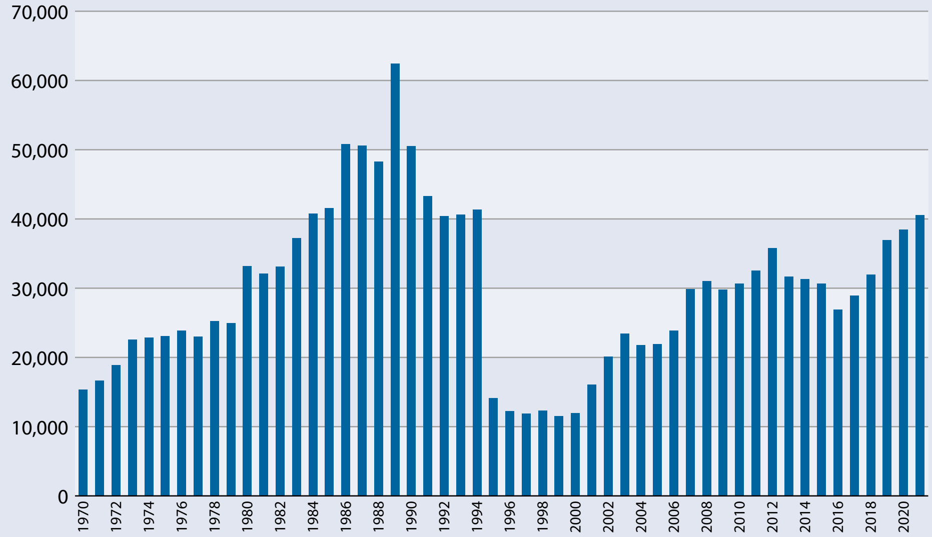


Source: Author's calculations based on the APO Productivity Database

- Like the proportion of manufacturing in GDP, labor productivity peaked in 1989 and then decreased, with a sharp decline particularly in 1995. Limited growth indicates challenges in industrial efficiency. However, unlike the proportion of manufacturing, which continued to decline afterward, productivity has been on an increasing trend through 2021.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



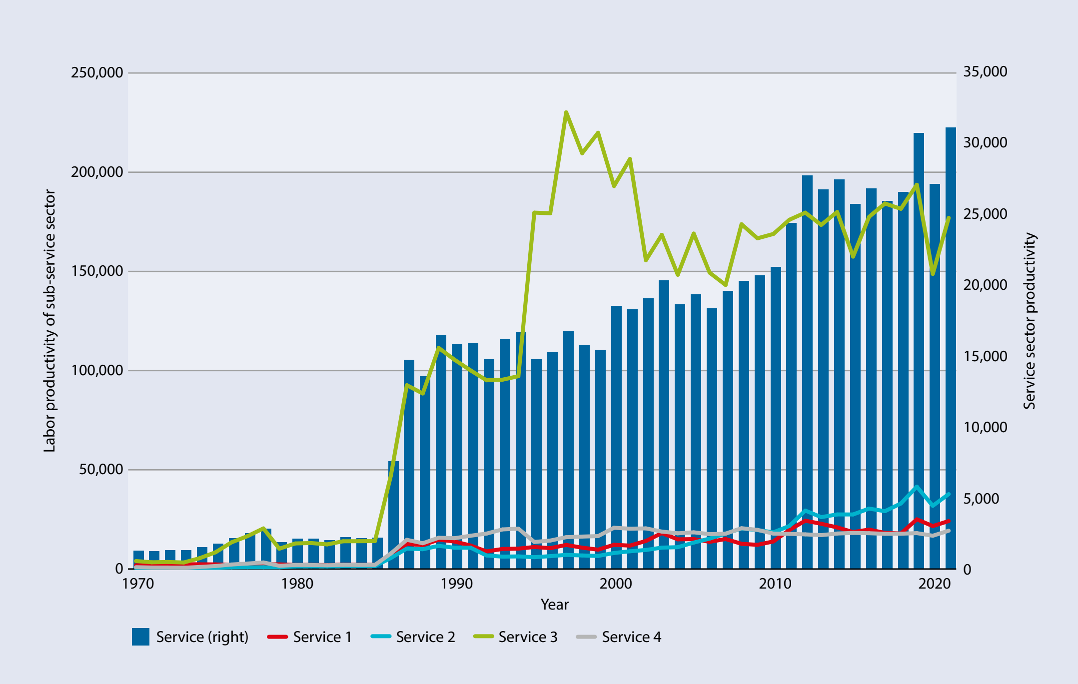
Source: Author's calculations based on the APO Productivity Database

<Service>

- Mongolia's service sector productivity remained relatively stable until the mid-1980s, after which it experienced a sharp increase. Following this rise, it displayed a gradual upward trend through 2020.

- Service Sector 3 (finance, real estate, renting, and business activities) exhibited significant volatility in labor productivity, peaking above 200,000 in the 2000s before declining and stabilizing at approximately 150,000 by 2020.

- The labor productivity of other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), started below 10,000 but demonstrated consistent growth, reaching approximately 20,000 by 2020.



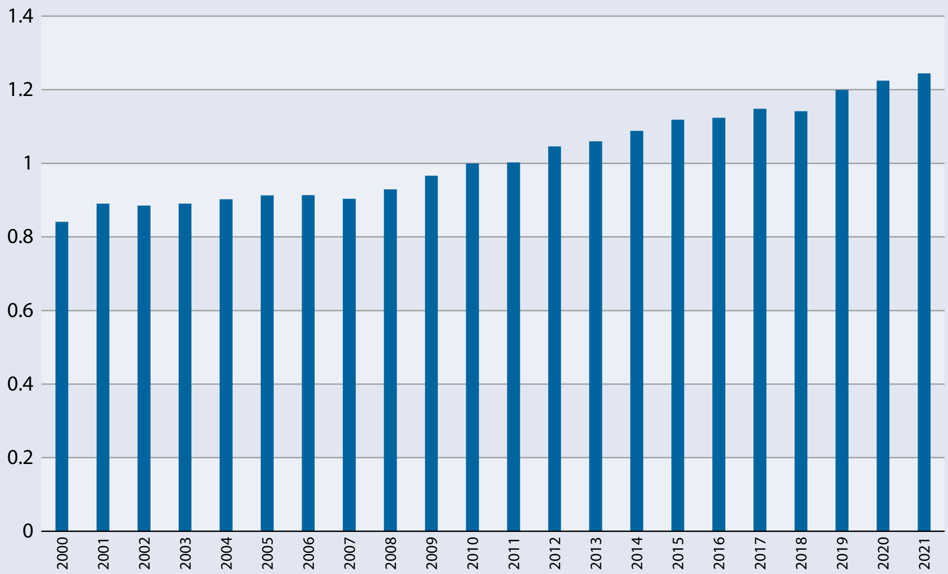
COUNTRY PROFILE: NEPAL

<Agriculture>

- Nepal shows a gradual increase in agricultural labor productivity, with steady improvement observed particularly after 2016.

FIGURE 1

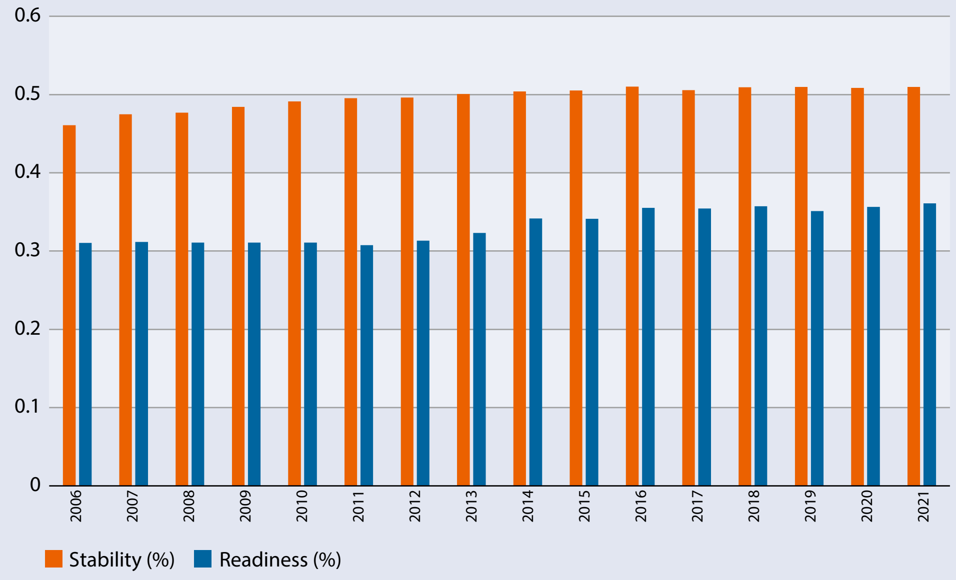
AGRICULTURAL LABOR PRODUCTIVITY



- Nepal displays a steady trend in Stability, while Readiness remains relatively stable with minor variations across the years.

FIGURE 2

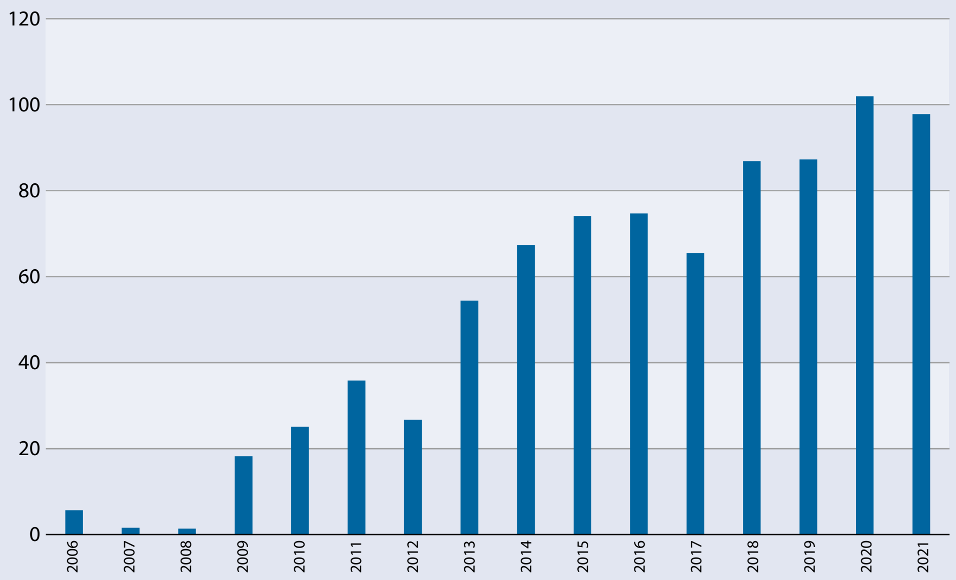
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Nepal has seen a steady increase in fertilizer consumption, particularly marked from the early 2000s, with consistent growth over the years.

FIGURE 3

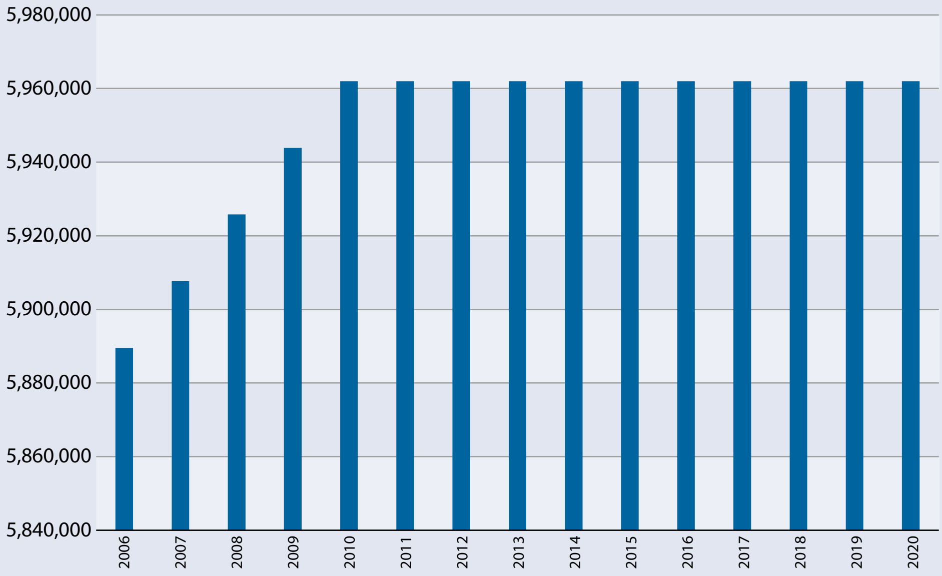
FERTILIZER CONSUMPTION



- Nepal has seen a gradual increase in forest area, especially from the early 2000s, indicating reforestation efforts.

FIGURE 4

FOREST AREA

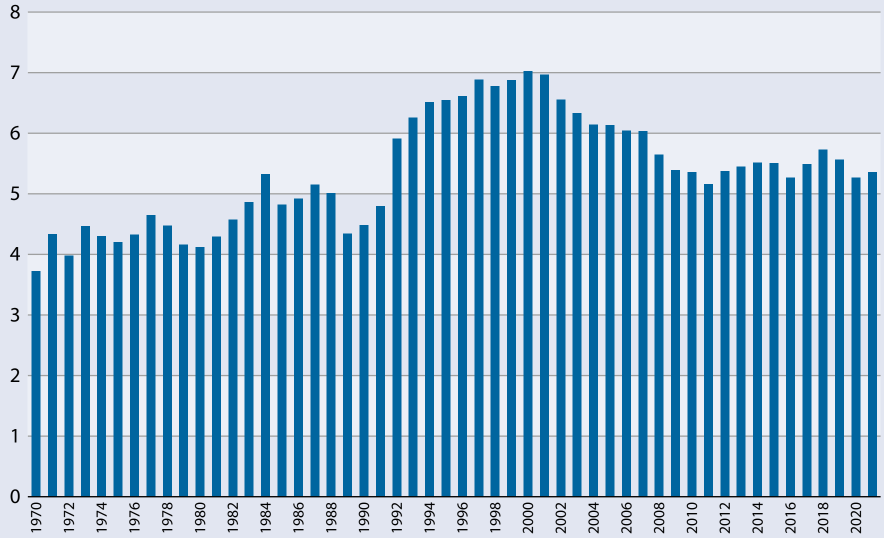


<Manufacturing>

- Manufacturing is relatively low, at less than 7% compared to other countries. It indicates a reliance on other sectors like agriculture. Despite some fluctuations, it was on an increasing trend from 1970 to 2000, and then decreased afterward.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

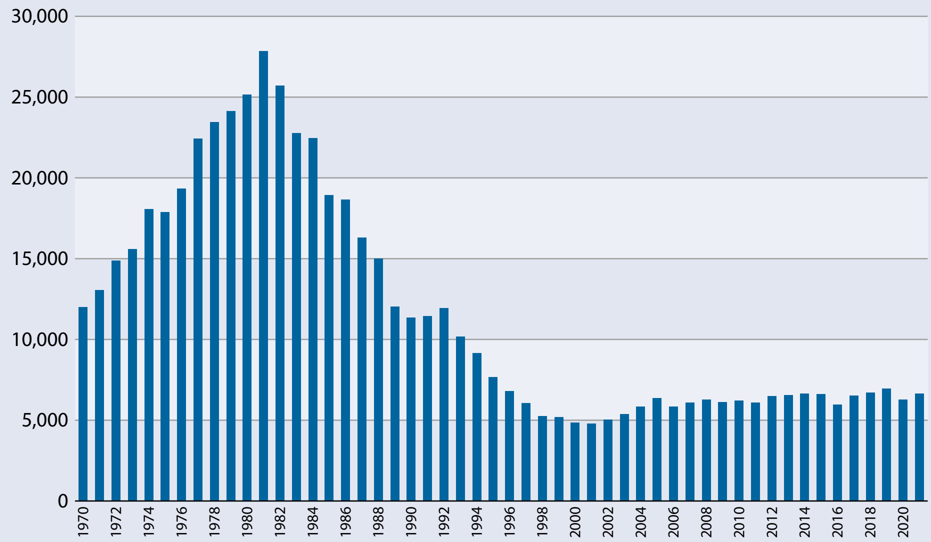


Source: Author's calculations based on the APO Productivity Database

- Labor productivity increased sharply from 1970 to 1981, but then decreased sharply until 2000. It has remained stagnant since 2000. Labor productivity growth is likely modest, reflecting constraints in industrial capacity or investment.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



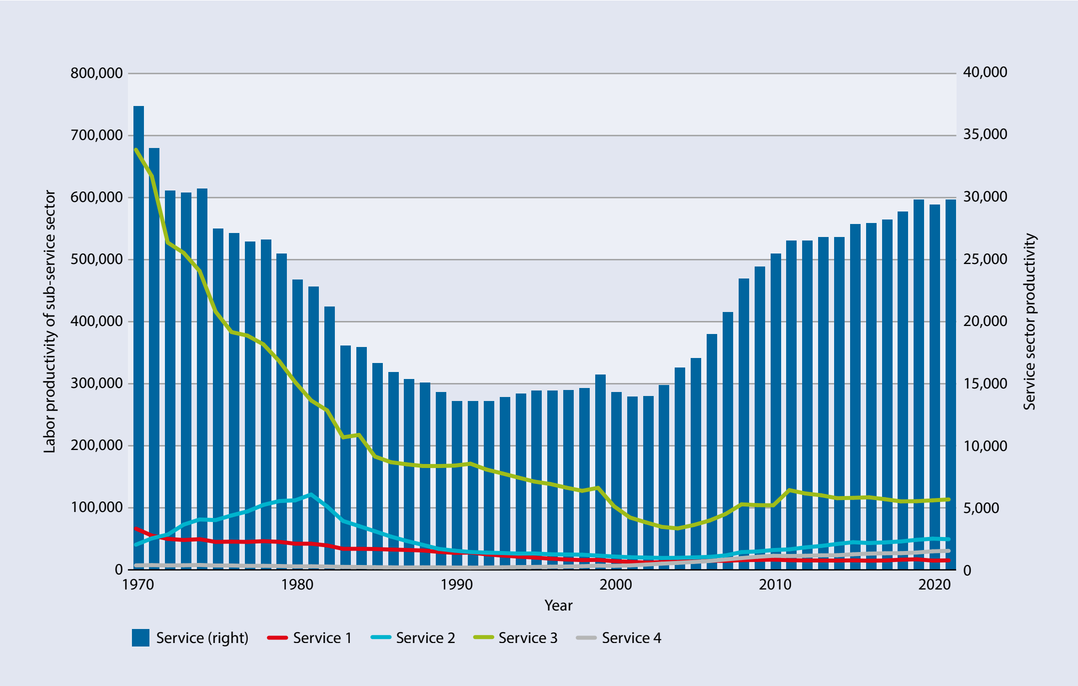
Source: Author's calculations based on the APO Productivity Database

<Service>

- Nepal's service sector productivity showed a downward trend until the mid-1990s but shifted to an upward trend afterward.

- Service Sector 3 (finance, real estate, renting, and business activities) initially exhibited higher labor productivity, but then experienced a sharp decline and eventually stabilized, aligning more closely with other sub-sectors in later years.

- The labor productivity of Service 2 (transport and communications) exhibited minor fluctuations in the early years but remained largely stable thereafter. Meanwhile, Service 1 (wholesale and retail trade) and Service 4 (community and personal services) showed minimal changes in productivity throughout the period.



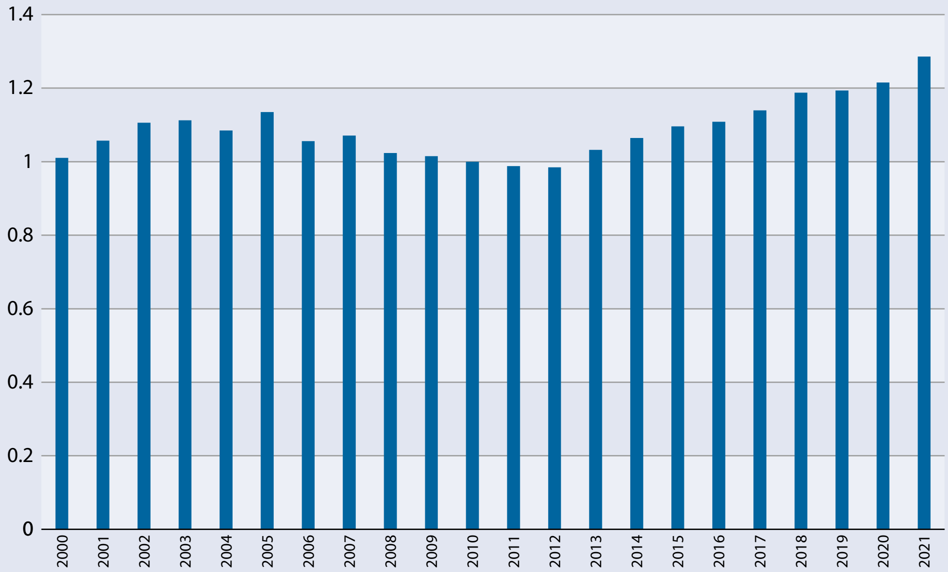
COUNTRY PROFILE: PAKISTAN

<Agriculture>

- Agricultural labor productivity in Pakistan has gradually risen since the 2000s. The sector has maintained stable growth up to 2021.

FIGURE 1

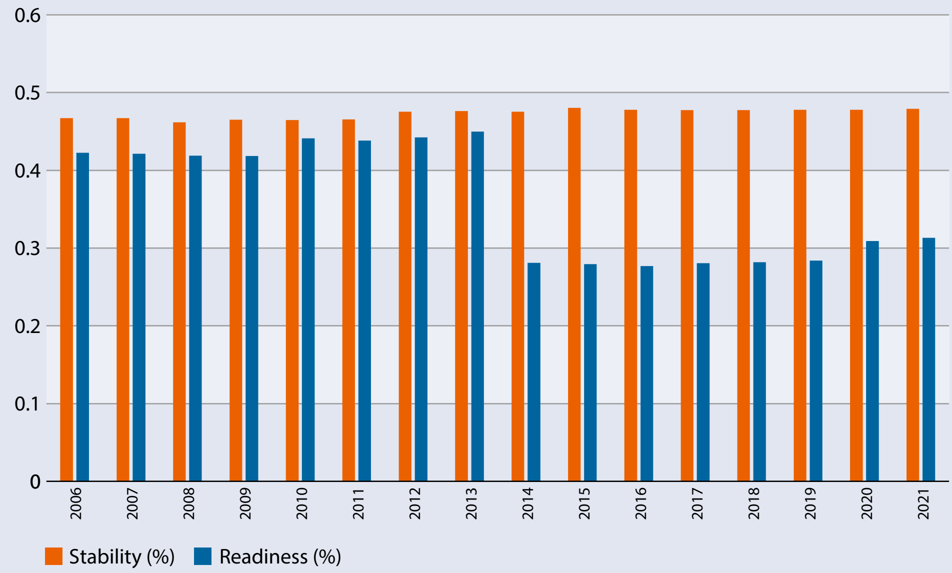
AGRICULTURAL LABOR PRODUCTIVITY



- Pakistan's Stability in climate adaptation remains consistently high, while Readiness fluctuates, particularly with dips between 2013 and 2018.

FIGURE 2

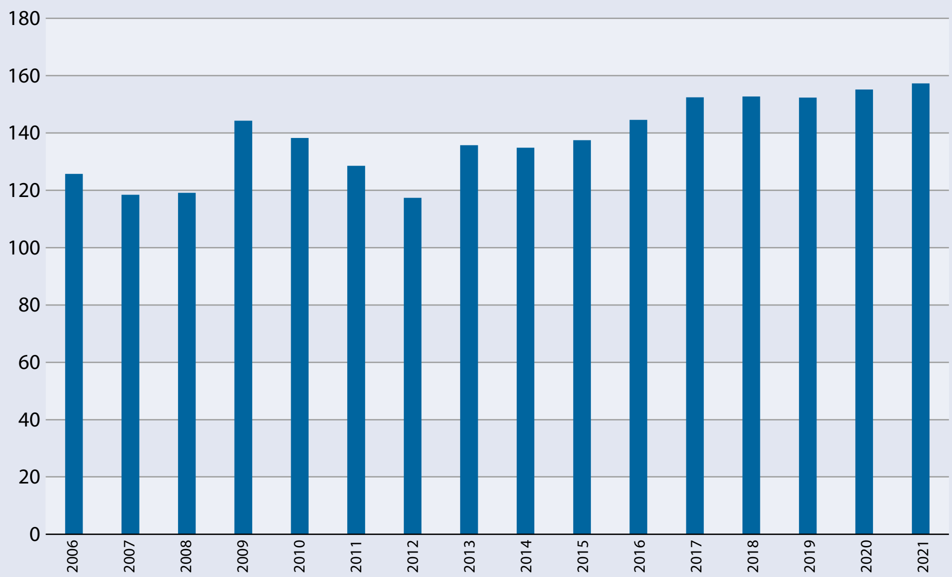
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Pakistan's fertilizer consumption has remained relatively stable, with slight increases but no major changes over time.

FIGURE 3

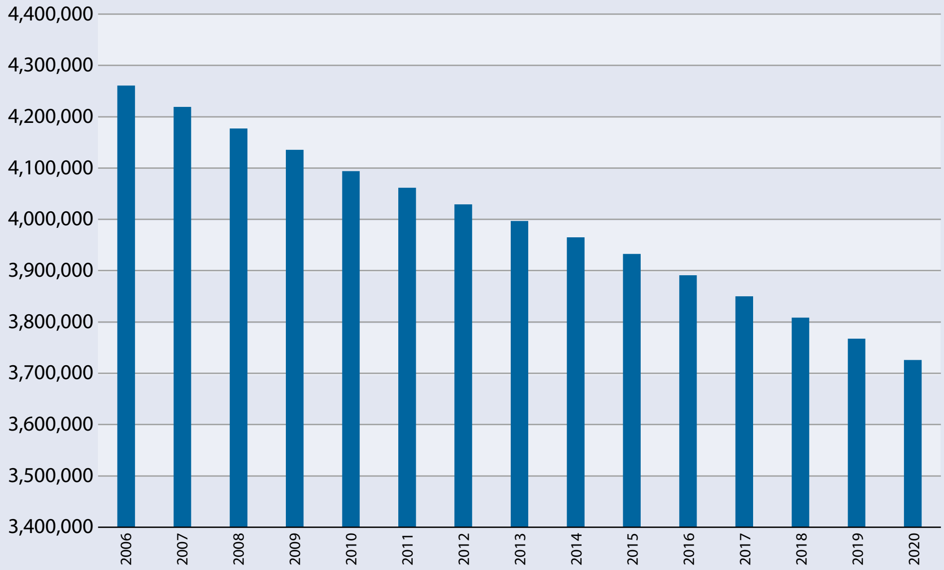
FERTILIZER CONSUMPTION



- Pakistan's forest area has declined over the years, showing a consistent decrease.

FIGURE 4

FOREST AREA

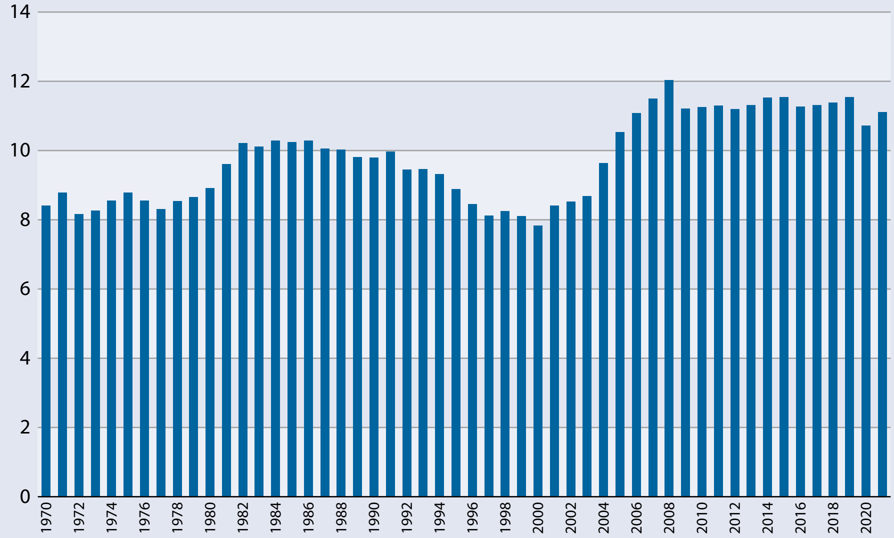


<Manufacturing>

- Manufacturing fluctuated from 1970 to the early 2000s, but increased sharply in the mid-2000s. Since then, it has maintained a steady level at around 11% up to 2021. These stable or decreasing trends indicate economic diversification.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

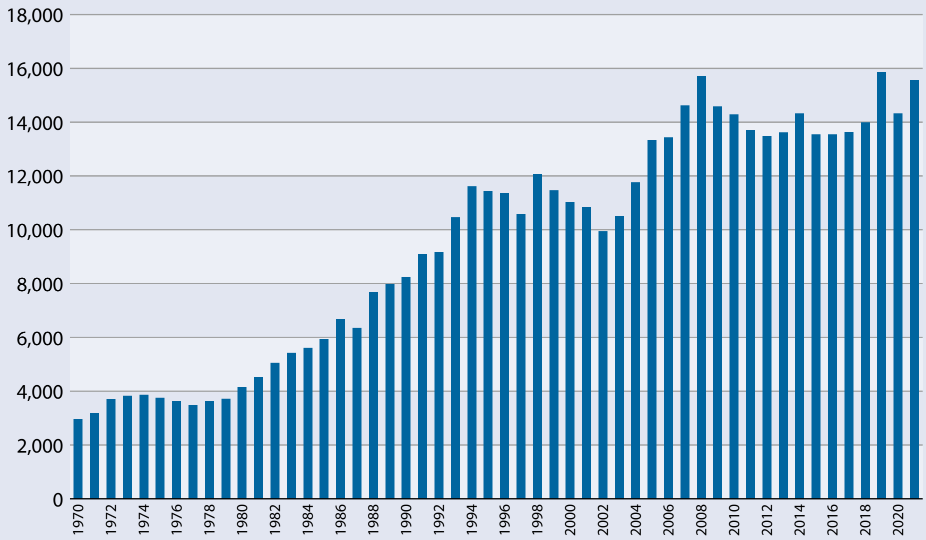


Source: Author's calculations based on the APO Productivity Database

- Unlike the relatively steady share of manufacturing in GDP, labor productivity has steadily increased since 1970. It increased significantly in the late 1980s and early 1990s, as well as in the mid to late 2000s. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development.

FIGURE 6

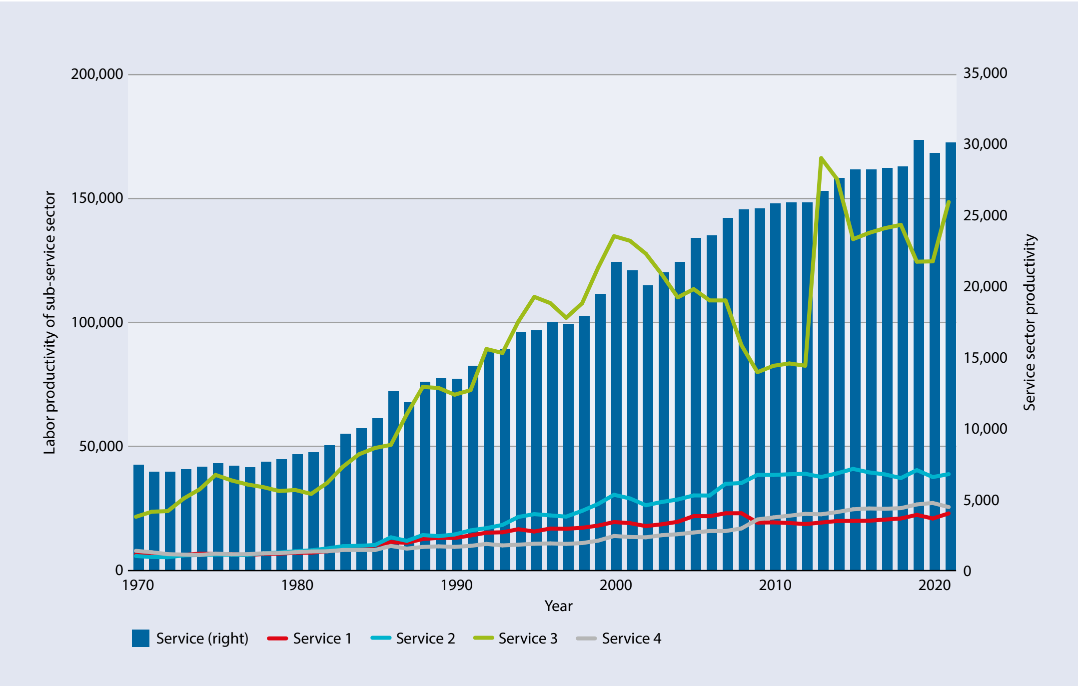
TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



Source: Author's calculations based on the APO Productivity Database

<Service>

- Pakistan's service sector productivity has steadily increased, starting around 10,000 in the 1970s and reaching approximately 30,000 by 2020.
- The labor productivity of Service Sector 3 (finance, real estate, renting, and business activities) experienced initial growth and fluctuations before stabilizing at approximately 100,000.
- The labor productivity of other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), remained below 50,000, with each sector exhibiting slight but steady growth over time.



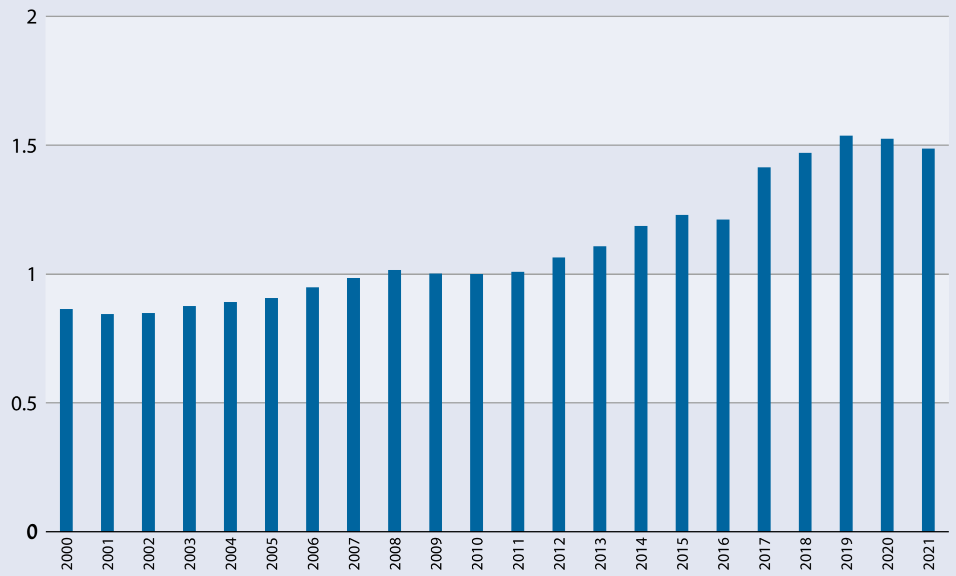
COUNTRY PROFILE: PHILIPPINES

<Agriculture>

- In the Philippines, agricultural labor productivity has consistently increased. The trend of steady improvement continued through 2021.

FIGURE 1

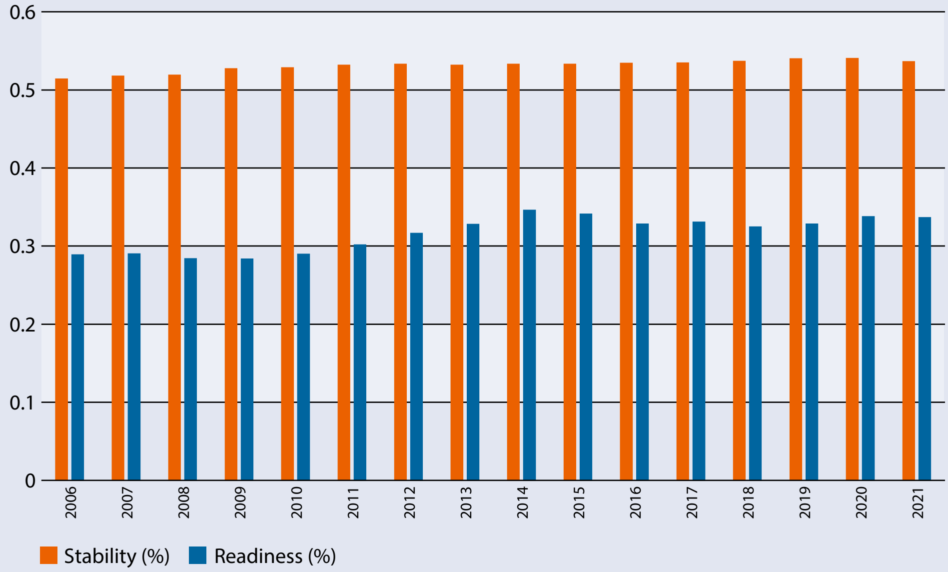
AGRICULTURAL LABOR PRODUCTIVITY



- The Philippines shows a steady level of Stability, while Readiness fluctuates slightly but remains generally stable.

FIGURE 2

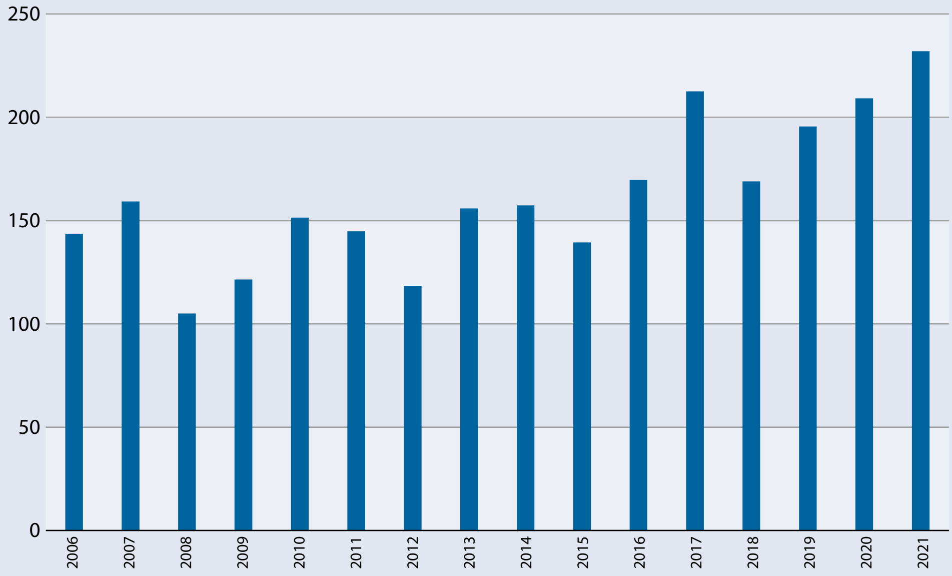
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- The Philippines shows a steady upward trend in fertilizer consumption, with consistent growth especially in recent years.

FIGURE 3

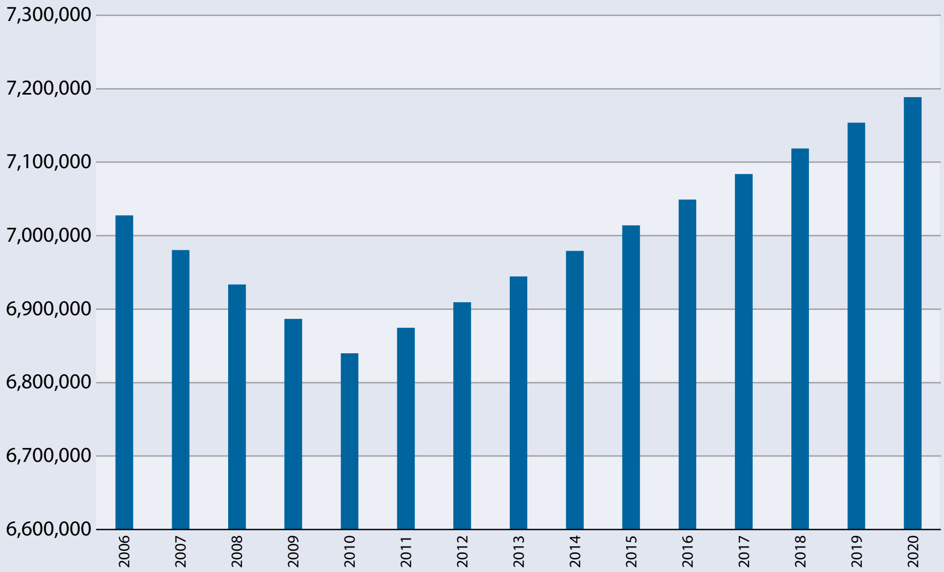
FERTILIZER CONSUMPTION



- The Philippines shows a fluctuating trend, with recent years showing an upward trend in forest area.

FIGURE 4

FOREST AREA

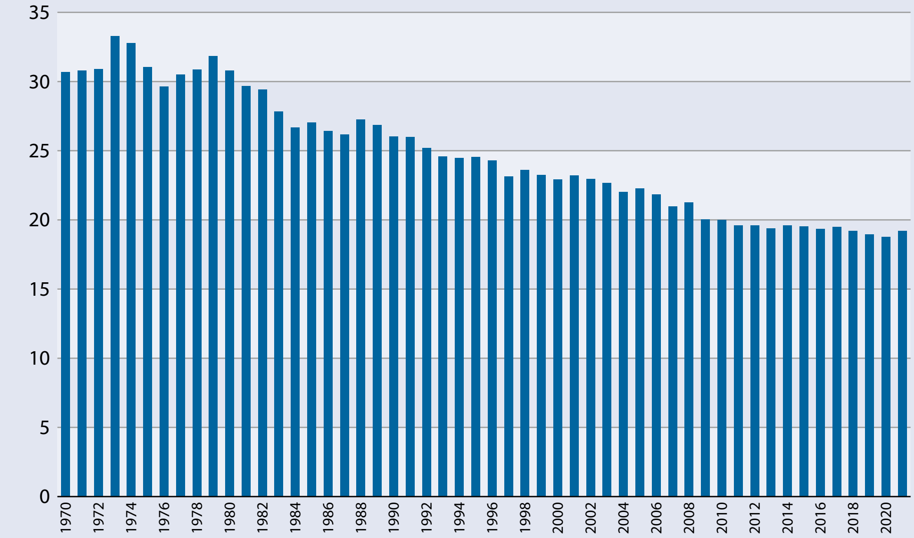


<Manufacturing>

- Manufacturing has shown a steady decline from about 30% in 1970, reaching approximately 18% as of 2021.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

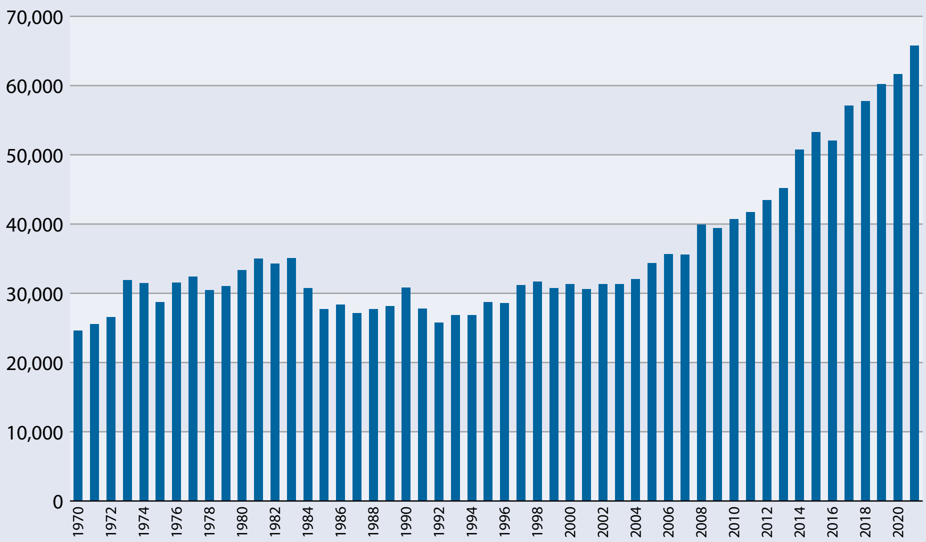


Source: Author's calculations based on the APO Productivity Database

- Unlike the steadily declining share of manufacturing in GDP, labor productivity has increased sharply since the 2000s, reaching a record high in 2021. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



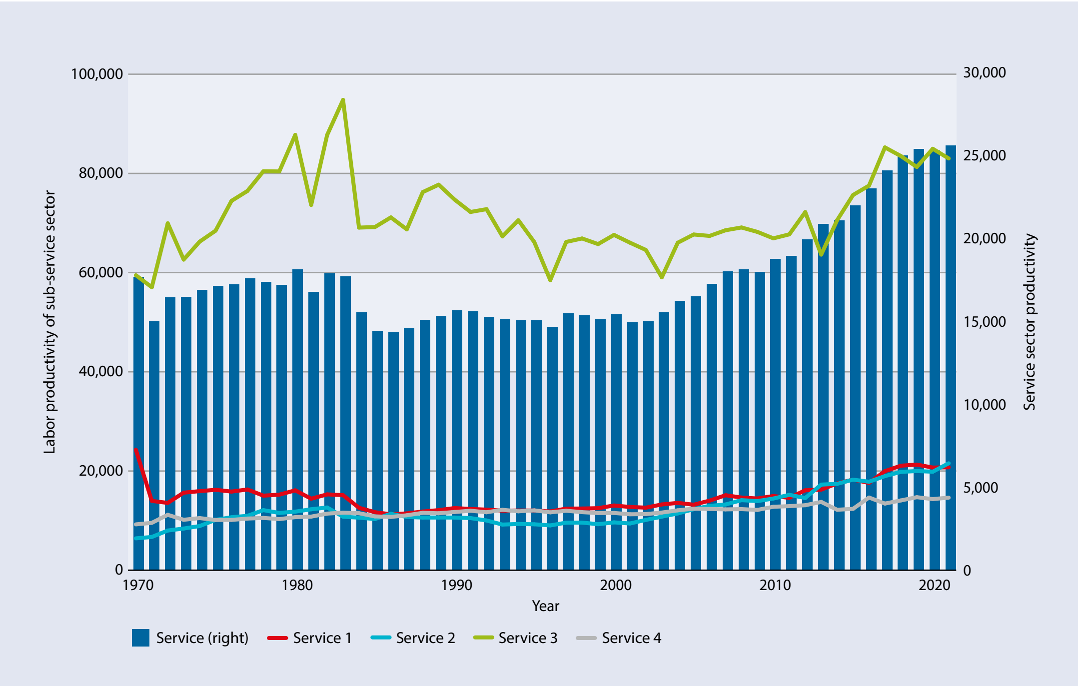
Source: Author's calculations based on the APO Productivity Database

<Service>

- The productivity of the Philippines' service sector remained relatively stable until the mid-2000s, after which it began to increase, eventually surpassing 20,000.

- The labor productivity of Service Sector 3 (finance, real estate, renting, and business activities) showed some volatility, peaking around 90,000 in the 1980s before stabilizing at approximately 75,000.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), have maintained labor productivity levels below 25,000, exhibiting steady and modest growth over time.



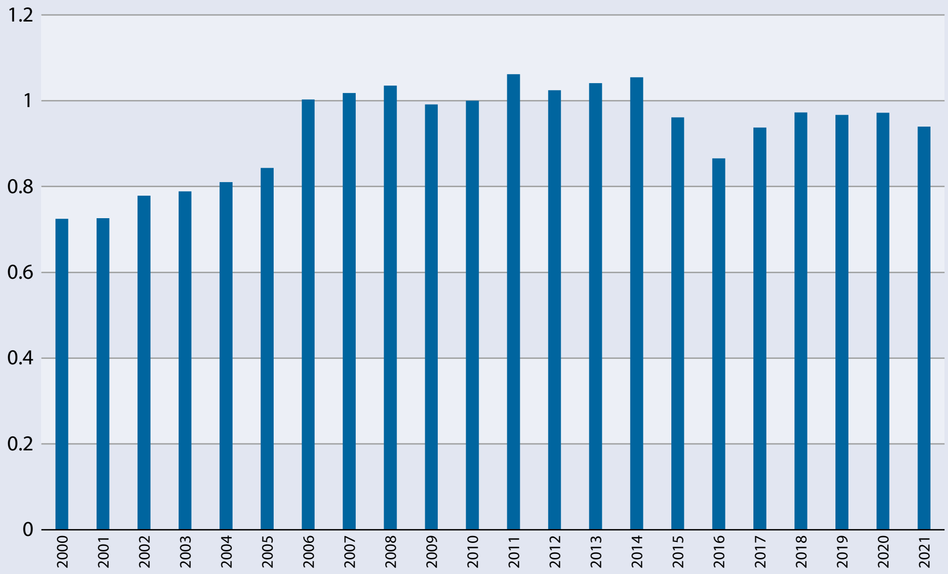
COUNTRY PROFILE: REPUBLIC OF CHINA

<Agriculture>

- Republic of China (ROC) shows a gradual increase in agricultural labor productivity, though recent years indicate a more stagnant trend.

FIGURE 1

AGRICULTURAL LABOR PRODUCTIVITY

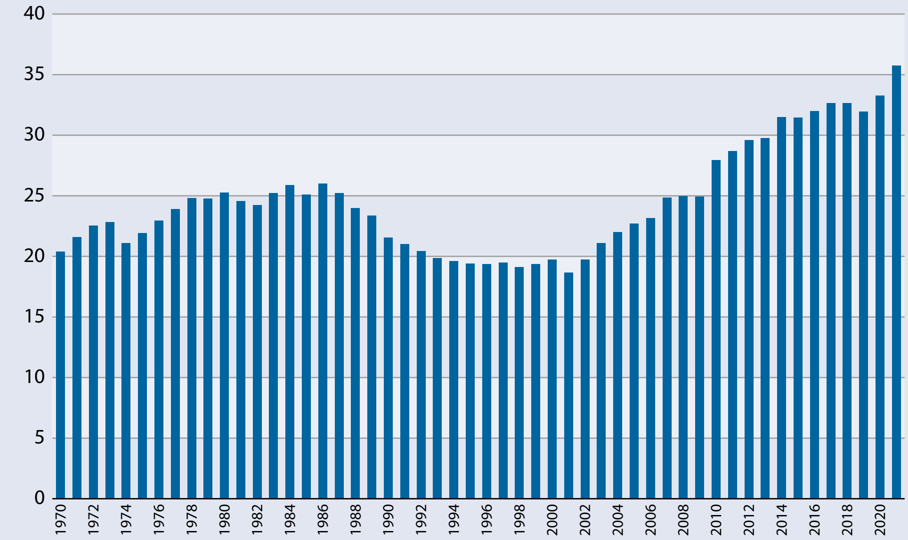


<Manufacturing>

- Manufacturing maintained a steady level in the 1970s and 1980s, then showed a decreasing trend in the 1990s. Subsequently, it shifted to an increasing trend, reaching a record high of about 36% in 2021.

FIGURE 2

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

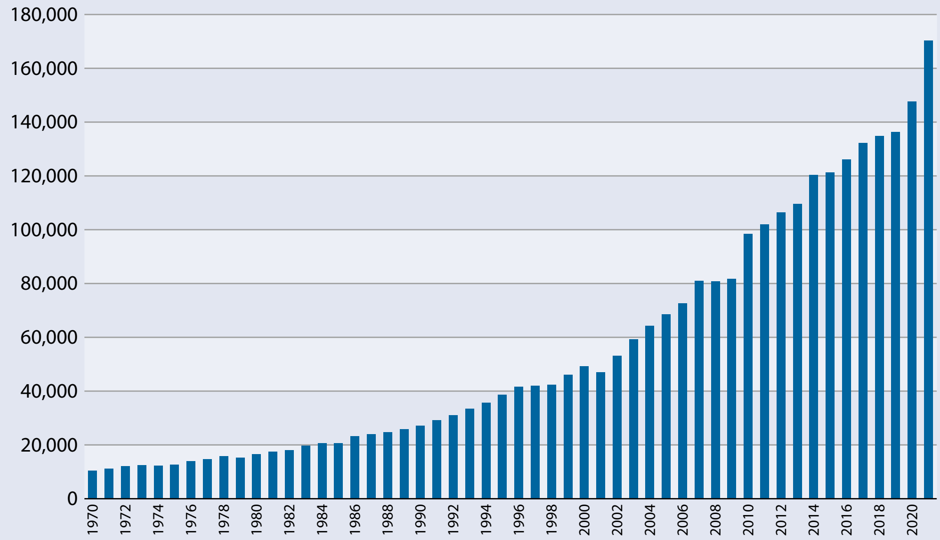


Source: Author's calculations based on the APO Productivity Database

- Unlike the trend in the share of manufacturing in GDP, labor productivity has steadily increased since 1970. In particular, it increased significantly in the 2010s, reaching a record high in 2021. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development. Also, significant growth reflects advanced practices.

FIGURE 3

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



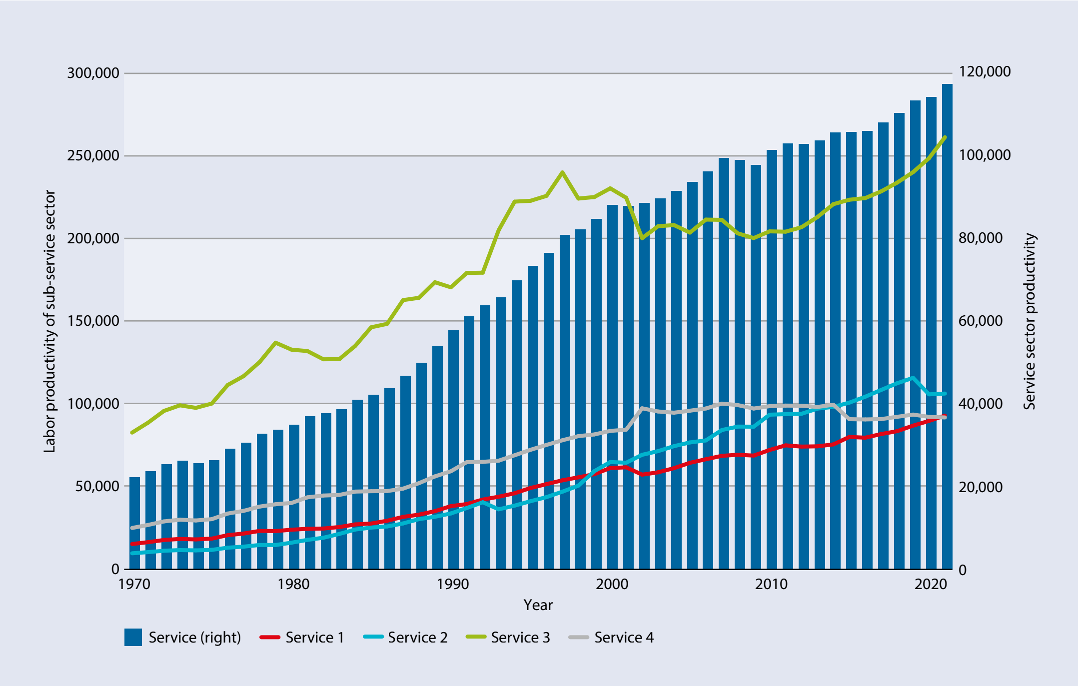
Source: Author's calculations based on the APO Productivity Database

<Service>

- The overall productivity in ROC's service sector has shown continuous growth, starting around 30,000 in the early 1970s and reaching nearly 120,000 by 2020.

- Service Sector 3 (finance, real estate, renting, and business activities) experienced significant growth in labor productivity, rising to approximately 250,000 by 2020.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), began with lower labor productivity levels and experienced steady growth, reaching approximately 100,000 by 2020.



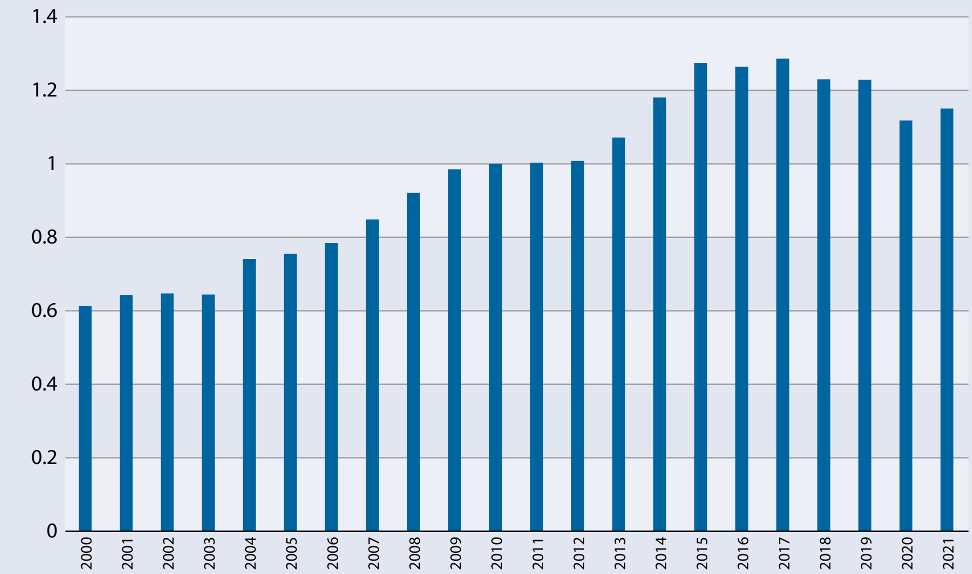
COUNTRY PROFILE: REPUBLIC OF KOREA

<Agriculture>

- In the Republic of Korea (ROK), agricultural labor productivity displayed steady growth initially. However, a slight downward trend has been noticeable from the mid-2010s.

FIGURE 1

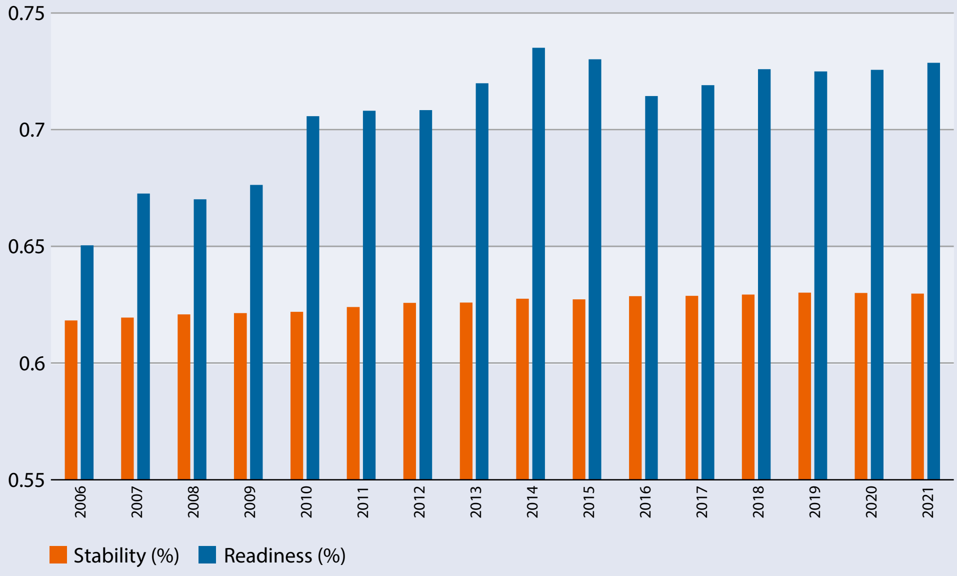
AGRICULTURAL LABOR PRODUCTIVITY



- ROK's Readiness score shows notable improvement over time, while Stability remains constant, highlighting increasing preparedness for climate adaptation.

FIGURE 2

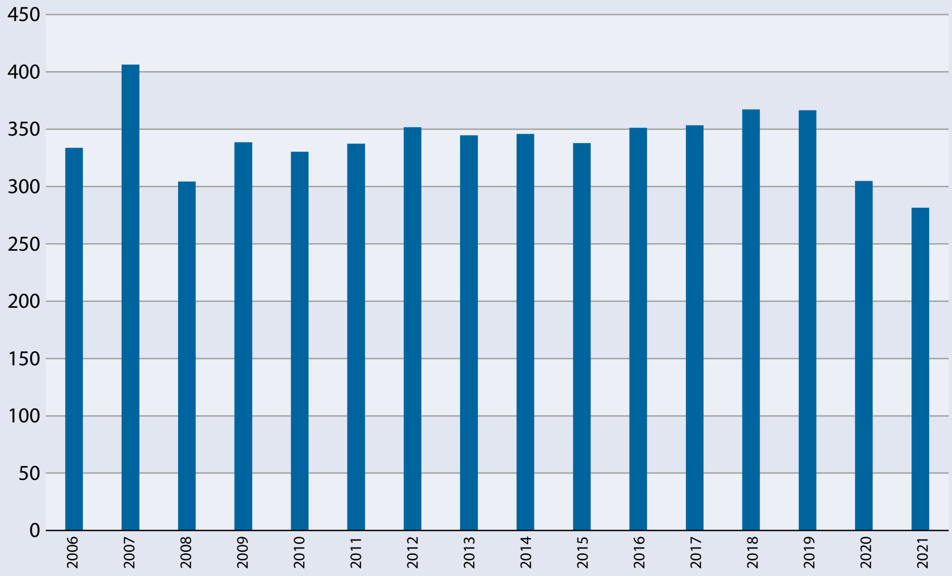
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Fertilizer consumption in ROK has remained mostly stable, with minor fluctuations around a consistent level since the early 2000s.

FIGURE 3

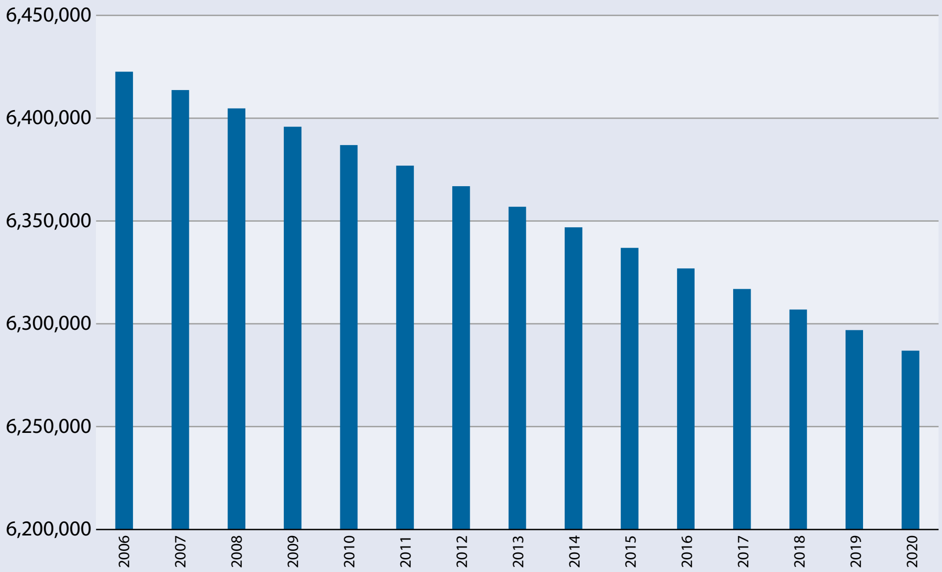
FERTILIZER CONSUMPTION



- ROK's forest area has shown a gradual decline, indicating slight reductions in forest cover.

FIGURE 4

FOREST AREA

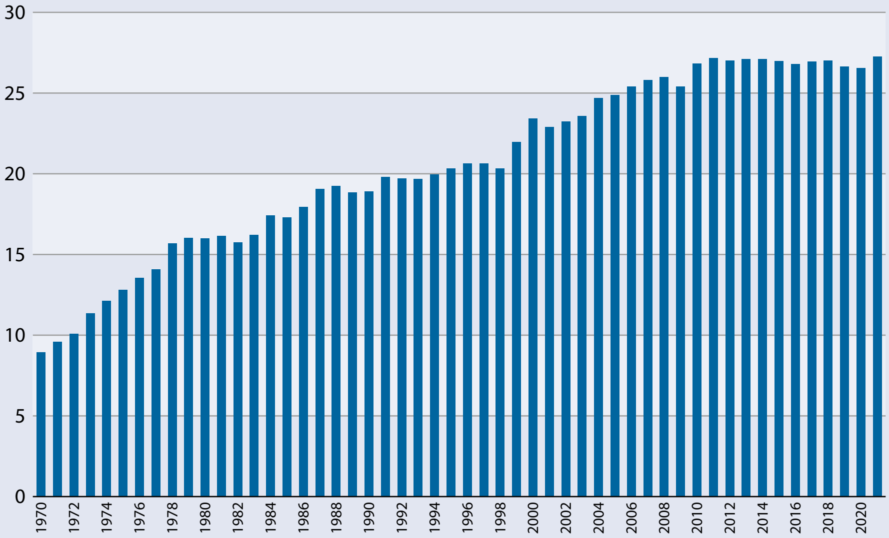


<Manufacturing>

- Manufacturing has shown a steadily increasing trend since 1970, reaching a record high of about 27% in 2021.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

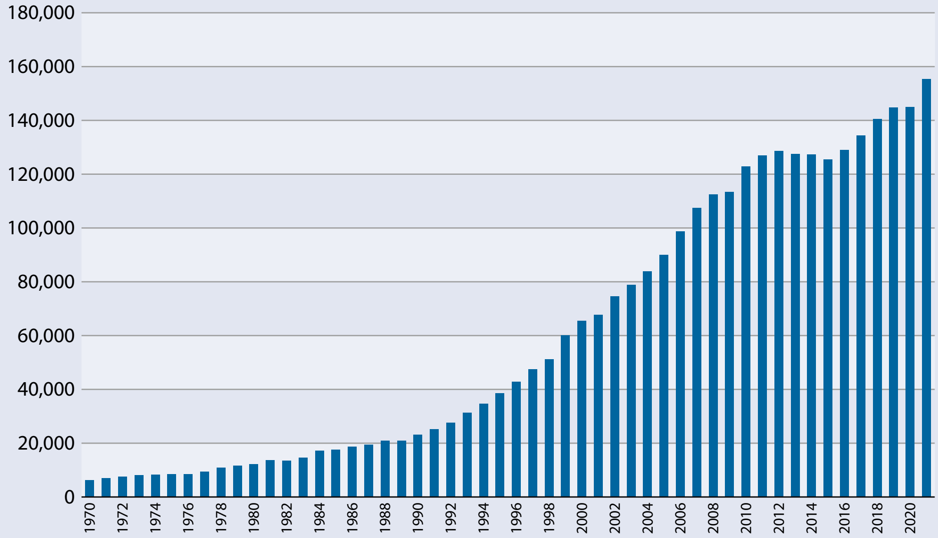


Source: Author's calculations based on the APO Productivity Database

- Similar to the trend in the share of manufacturing in GDP, labor productivity has also steadily increased. Especially since the 1990s, it has increased sharply. Although it somewhat stagnated in the early 2010s due to the aftermath of the global financial crisis, it has shown a sharply increasing trend again from the late 2010s. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development. Also, significant growth reflects technological advancements.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



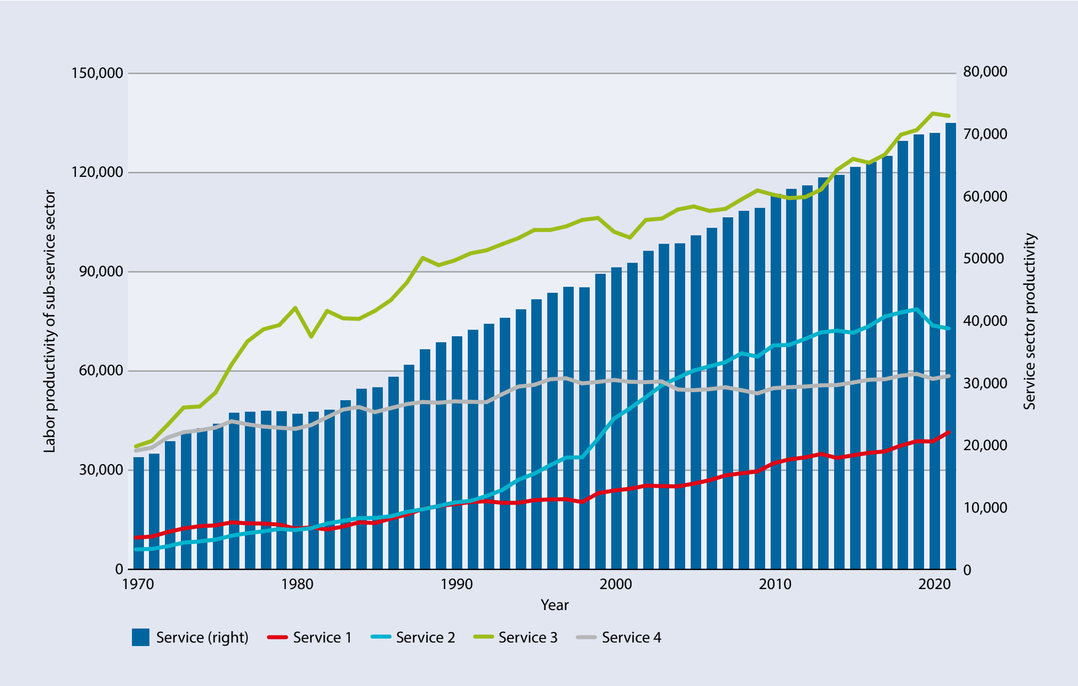
Source: Author's calculations based on the APO Productivity Database

<Service>

- ROK's service sector productivity has risen consistently, beginning around 20,000 in the early 1970s and climbing above 60,000 by 2020.

- Service Sector 3 (finance, real estate, renting, and business activities) demonstrates a steady rise in labor productivity, eventually reaching at approximately 150,000.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), exhibited gradual growth in labor productivity, with Service 2 notably reaching approximately 75,000 by 2020.



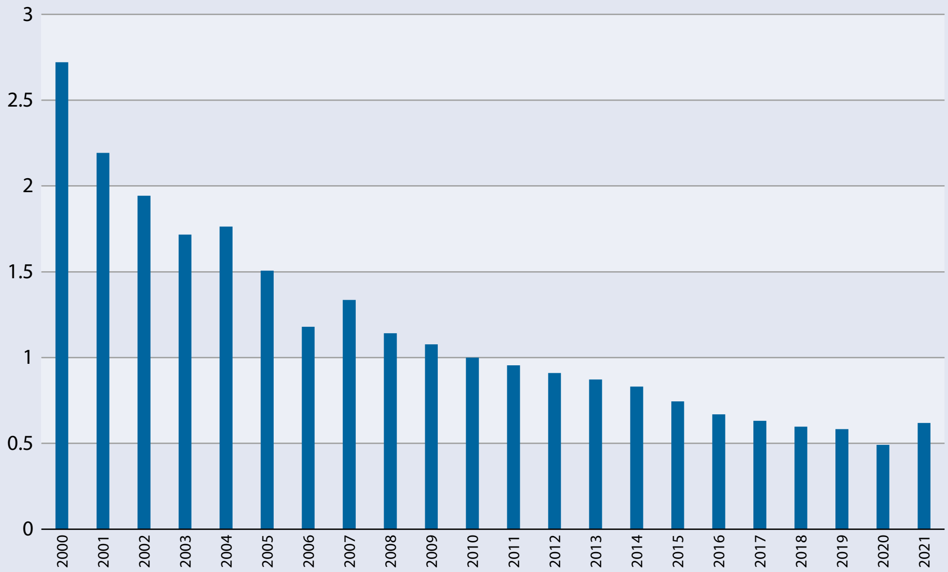
COUNTRY PROFILE: SINGAPORE

<Agriculture>

- Unlike most other countries, Singapore has experienced a noticeable decline in agricultural labor productivity. This downward trend is particularly pronounced after 2016.

FIGURE 1

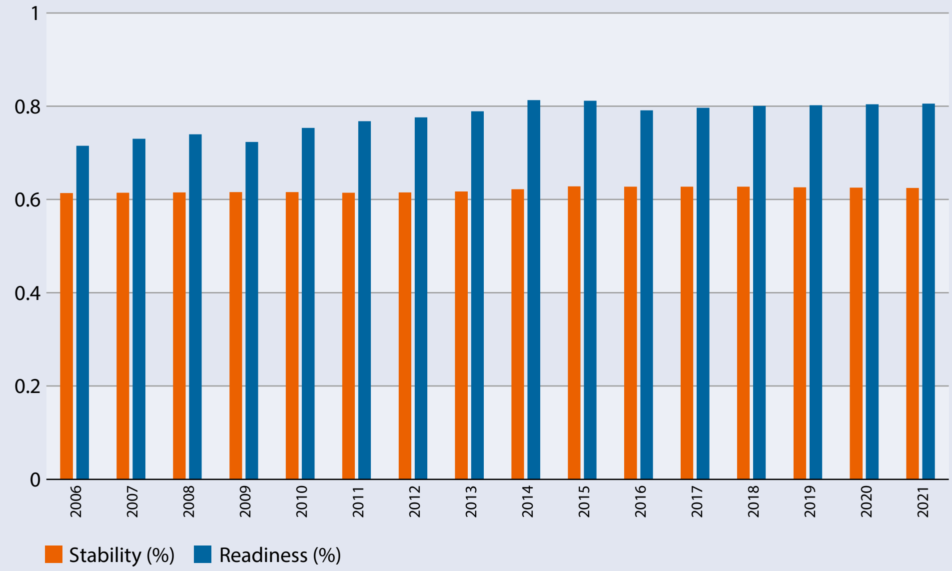
AGRICULTURAL LABOR PRODUCTIVITY



- Singapore maintains a consistent Stability level, with Readiness showing slight fluctuations, indicating a stable climate response approach.

FIGURE 2

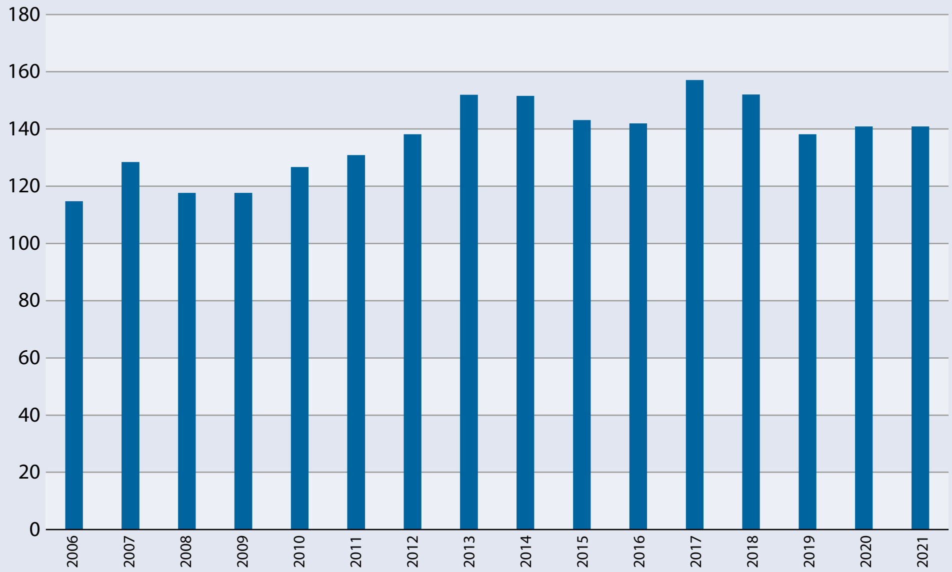
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Fertilizer consumption in Singapore remains stable with no significant changes, reflecting a low and consistent level of agricultural inputs.

FIGURE 3

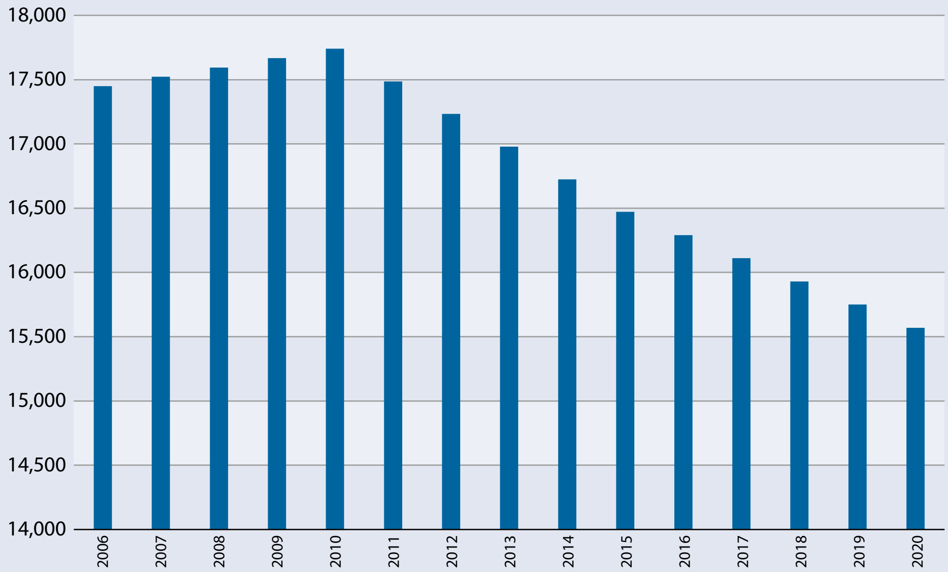
FERTILIZER CONSUMPTION



- Singapore's forest area has shown a slight decline, reflecting minor reductions in forest cover.

FIGURE 4

FOREST AREA

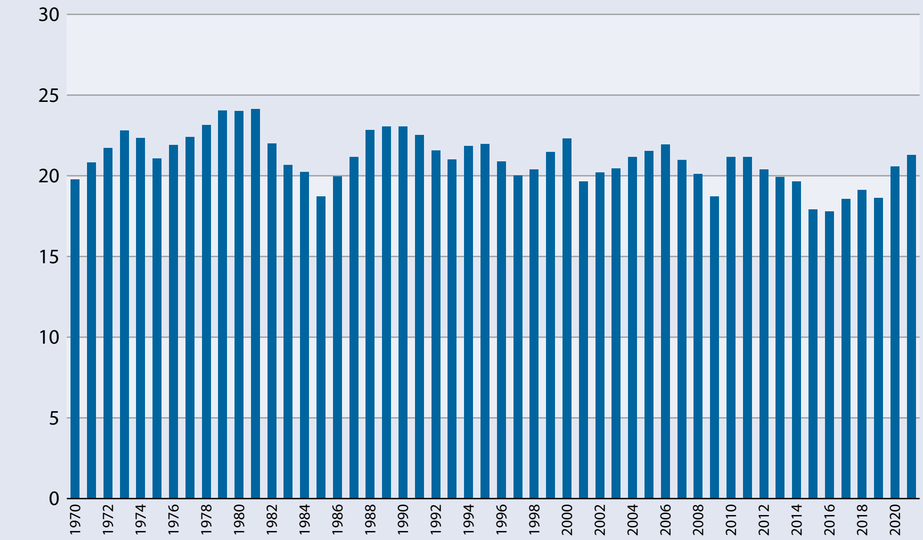


<Manufacturing>

- Manufacturing has fluctuated between approximately 17% and 24%. It generally shows a decreasing trend due to a shift towards services.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

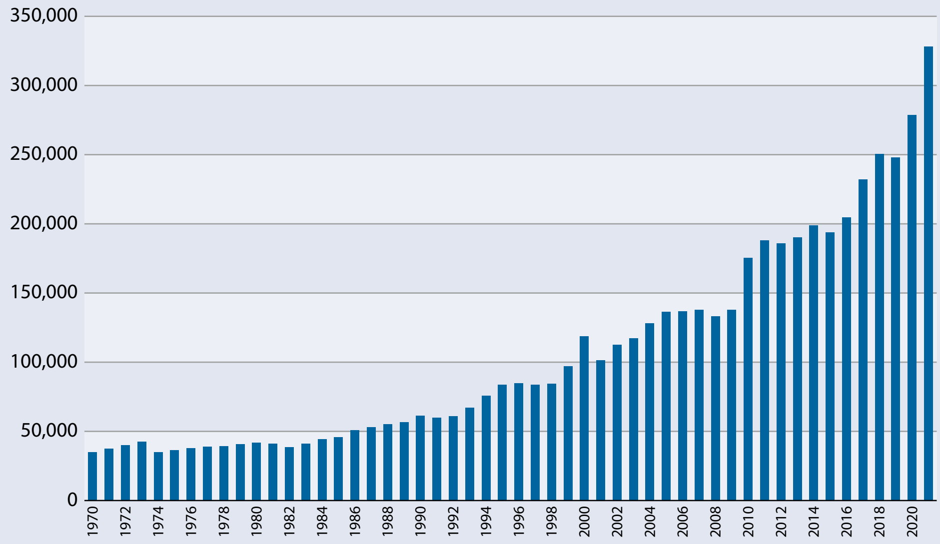


Source: Author's calculations based on the APO Productivity Database

- Unlike the trend in the share of manufacturing in GDP, labor productivity has steadily increased since 1970. In particular, it increased significantly in the 2010s, reaching a record high in 2021 due to a focus on high-tech industries. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development.

FIGURE 6

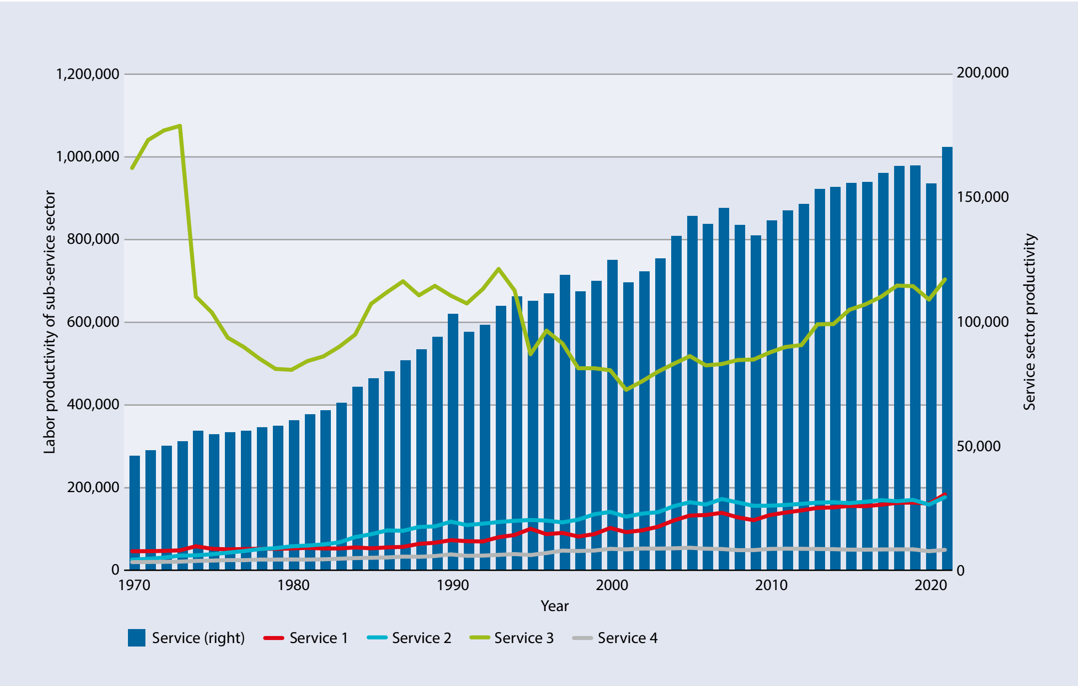
TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



Source: Author's calculations based on the APO Productivity Database

<Service>

- Singapore's service sector productivity has shown rapid growth, starting below 50,000 in the 1970s and reaching over 150,000 by 2020.
- Service Sector 3 (finance, real estate, renting, and business activities) exhibits significant volatility in labor productivity, starting above 900,000 before declining and stabilizing around 600,000 in recent years.
- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), began with much lower productivity levels but grew steadily.



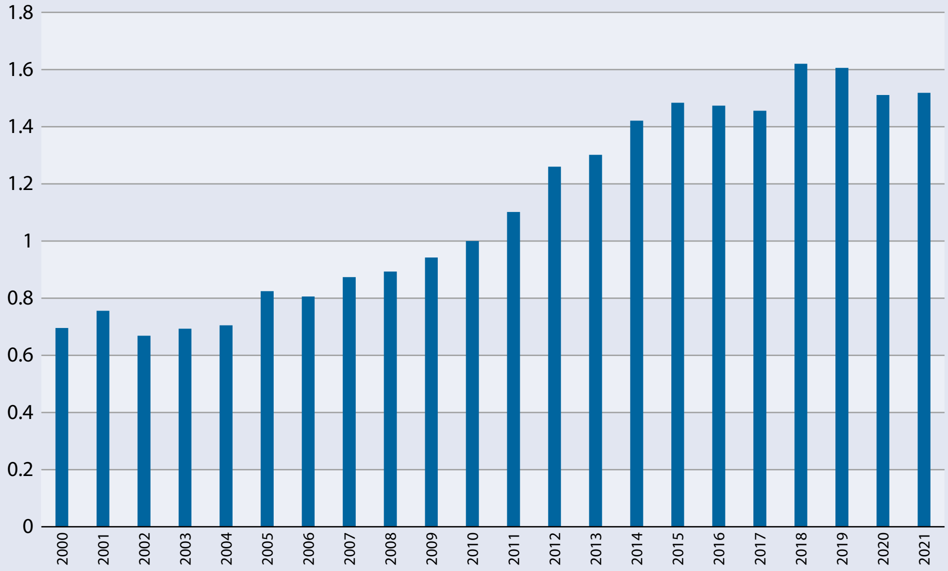
COUNTRY PROFILE: SRI LANKA

<Agriculture>

- Sri Lanka shows a gradual upward trend in agricultural labor productivity. Improvements have continued, especially after 2016.

FIGURE 1

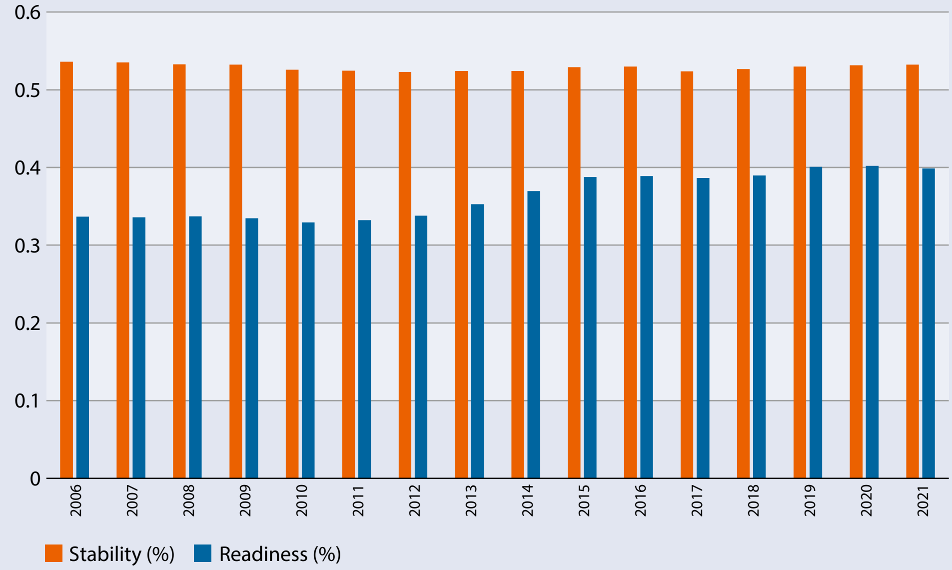
AGRICULTURAL LABOR PRODUCTIVITY



- Sri Lanka displays stable Stability scores, with Readiness showing minor fluctuations, maintaining a balanced trend in climate change preparedness.

FIGURE 2

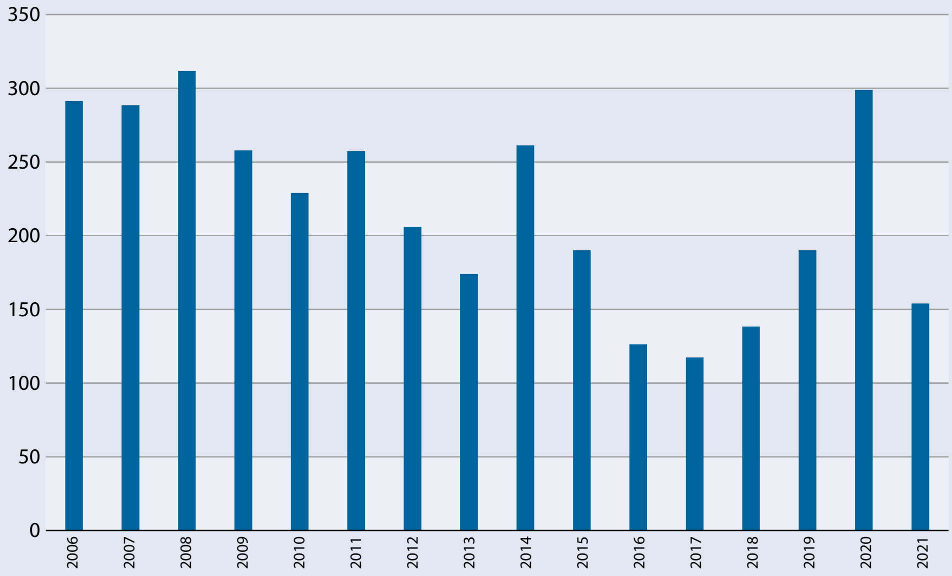
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- In Sri Lanka, fertilizer consumption shows fluctuations but generally maintains a steady trend, with a slight increase toward the end of the period.

FIGURE 3

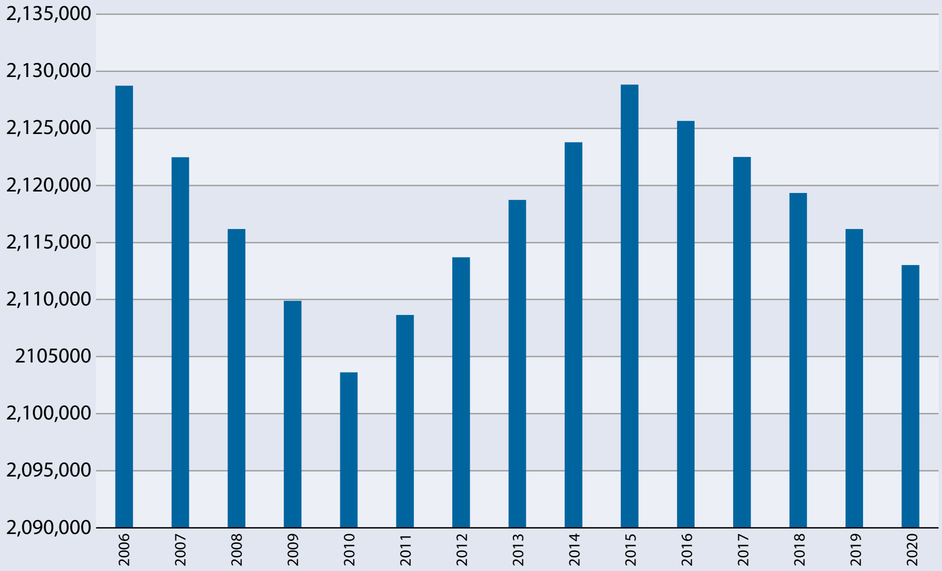
FERTILIZER CONSUMPTION



• Sri Lanka's forest area shows some fluctuation but generally maintains a downward trend in recent years.

FIGURE 4

FOREST AREA

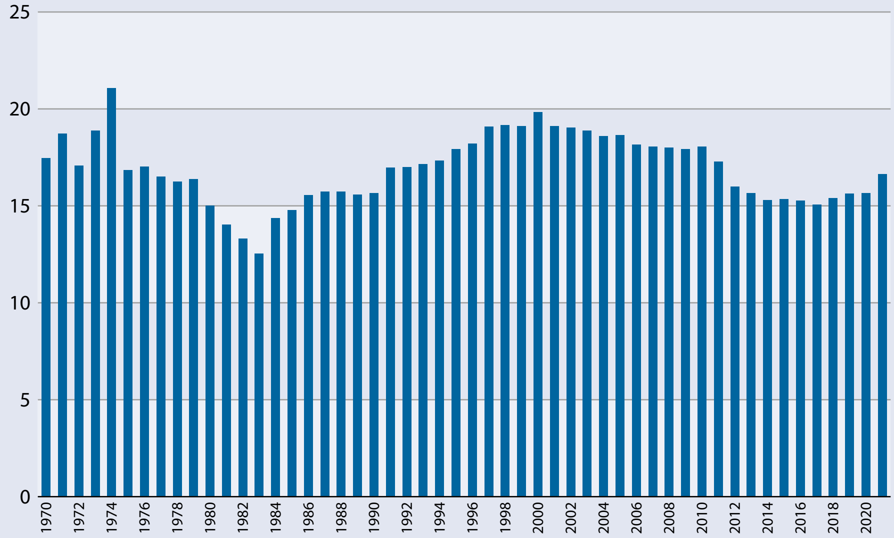


<Manufacturing>

- During the analysis period, manufacturing has shown a trend of fluctuating between approximately 15% and 20%. In the early 1980s, it fell to a record low of about 13%, but then rebounded until 2000. After that, it showed a declining trend until the late 2010s, but has been rebounding again in the 2020s. Fluctuations indicate varied development phases.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

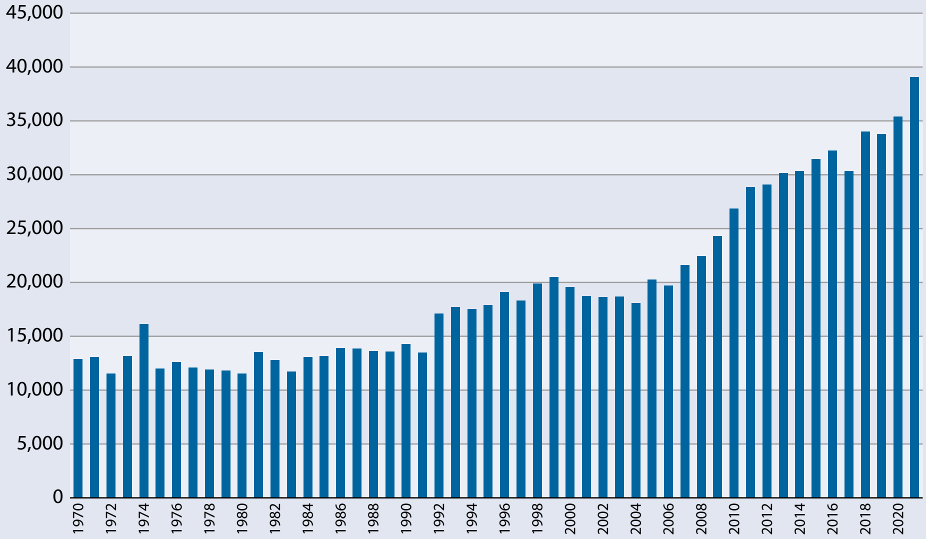


Source: Author's calculations based on the APO Productivity Database

- Unlike the trend in the share of manufacturing in GDP, labor productivity has shown a continuously increasing trend since the 1990s. In particular, it increased sharply in the 2010s. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



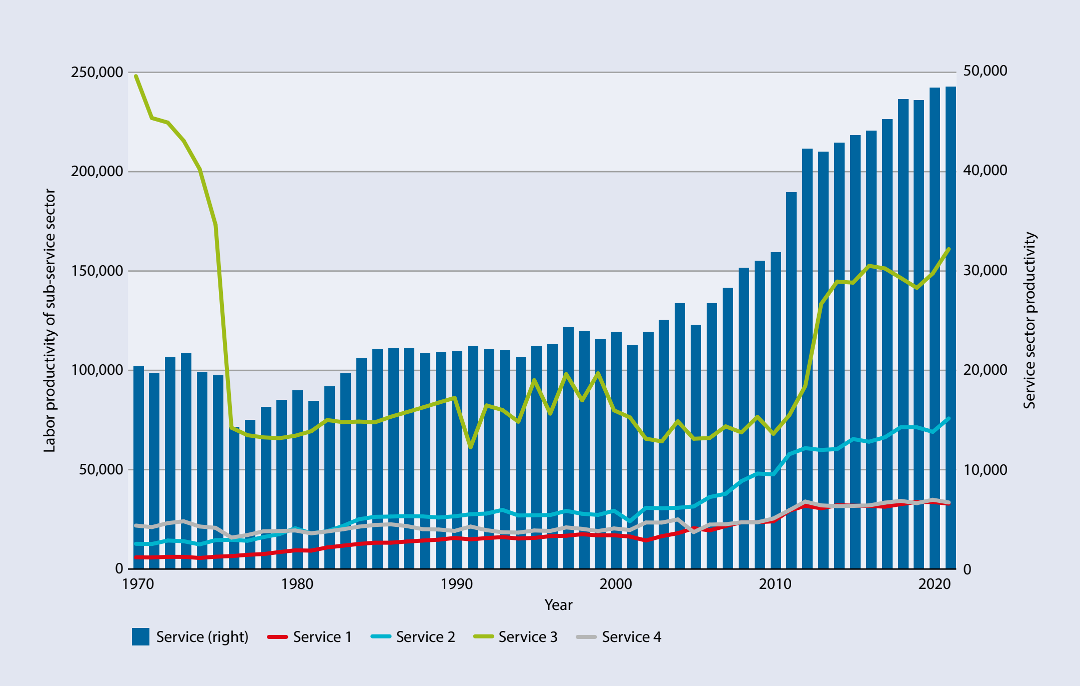
Source: Author's calculations based on the APO Productivity Database

<Service>

- Sri Lanka's service sector productivity remained stable until the mid-2000s, after which it began to grow steadily, starting from around 20,000 and reaching nearly 50,000 by 2020.

- The labor productivity of Service Sector 3 (finance, real estate, renting, and business activities) initially peaked above 250,000 in the early 1980s but then declined, stabilizing around 150,000 by the 2010s.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), maintained lower productivity levels, around 50,000, with steady growth over time.



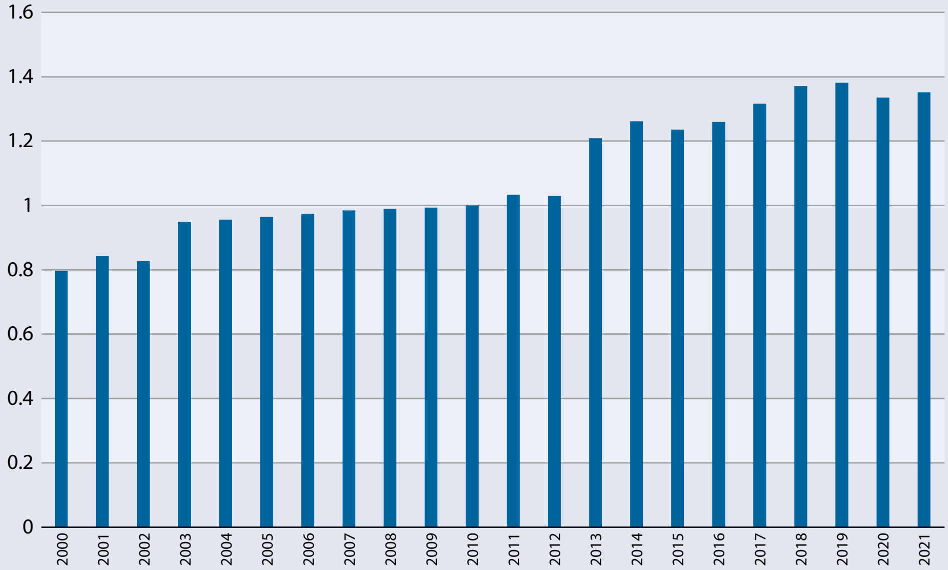
COUNTRY PROFILE: THAILAND

<Agriculture>

- Thailand shows a moderate upward trend in agricultural labor productivity. The sector has maintained consistent growth since 2016.

FIGURE 1

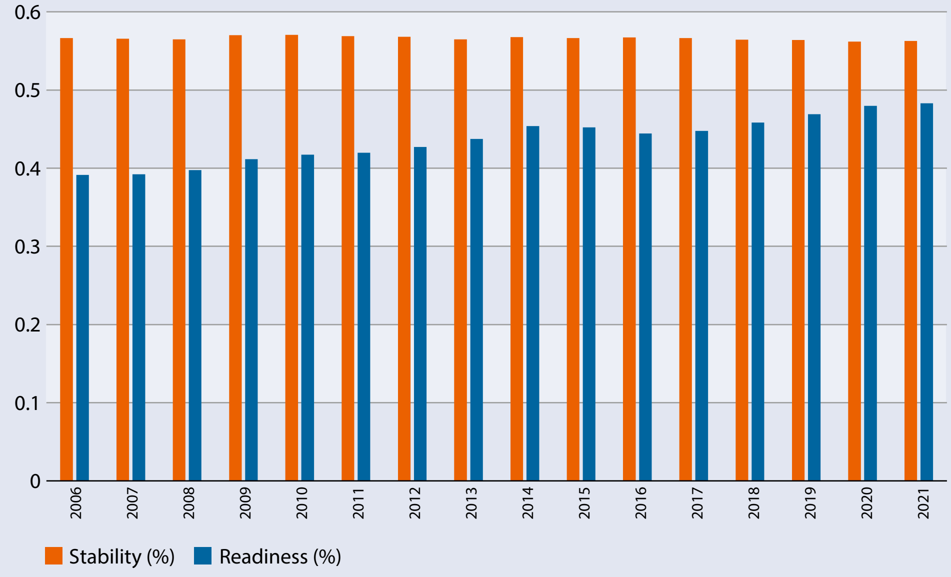
AGRICULTURAL LABOR PRODUCTIVITY



- Thailand exhibits consistent Stability, while Readiness has shown slight improvements, indicating a balanced trend in climate adaptation.

FIGURE 2

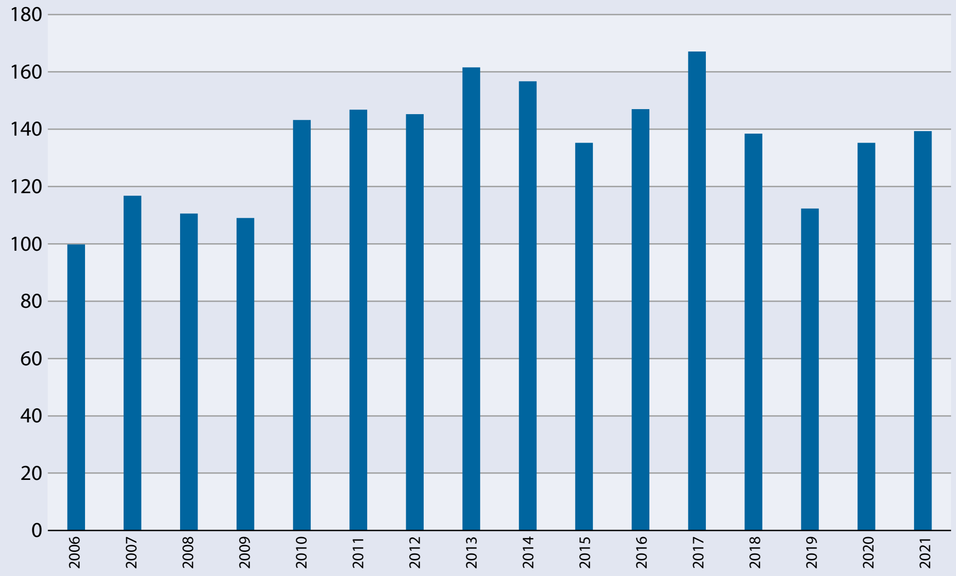
CLIMATE CHANGE ADAPTATION: STABILITY, READINESS



- Thailand shows a relatively stable pattern in fertilizer consumption, with minor fluctuations around a consistent average level.

FIGURE 3

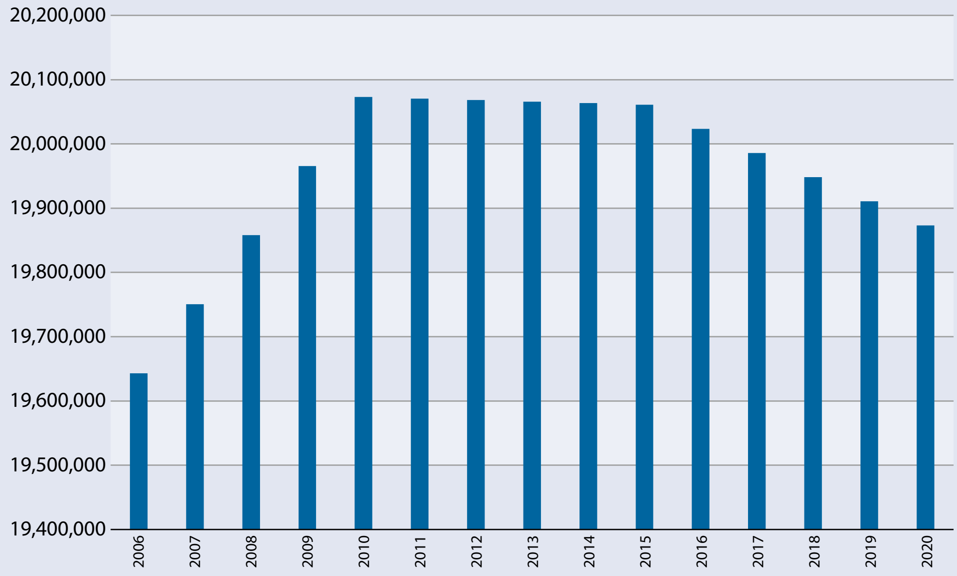
FERTILIZER CONSUMPTION



- Thailand's forest area fluctuates, with an overall increase in recent years.

FIGURE 4

FOREST AREA

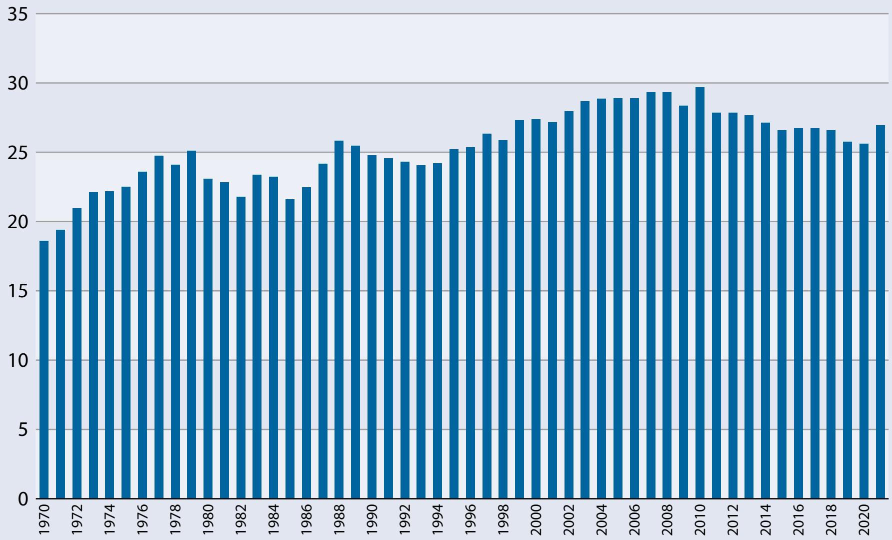


<Manufacturing>

- Although there have been fluctuations during the analysis period, manufacturing has been on a relatively increasing trend. A growth trend indicates industrialization. A tendency of decrease can be seen in the early 1980s, early 1990s, and early 2010s.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

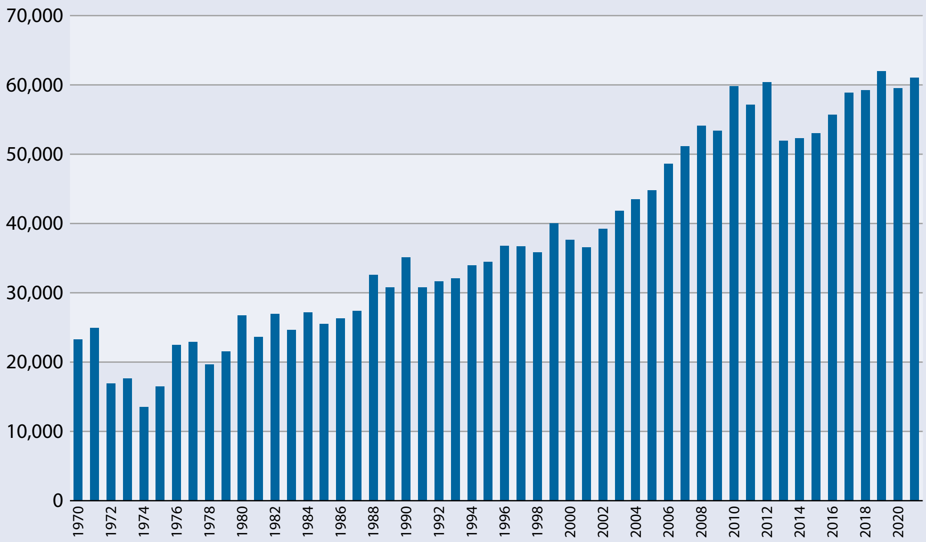


Source: Author's calculations based on the APO Productivity Database

- Unlike the fluctuating trend in the share of manufacturing in GDP, labor productivity has shown a sharply increasing trend since the mid-1970s, and in particular increased sharply in the 2000s. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



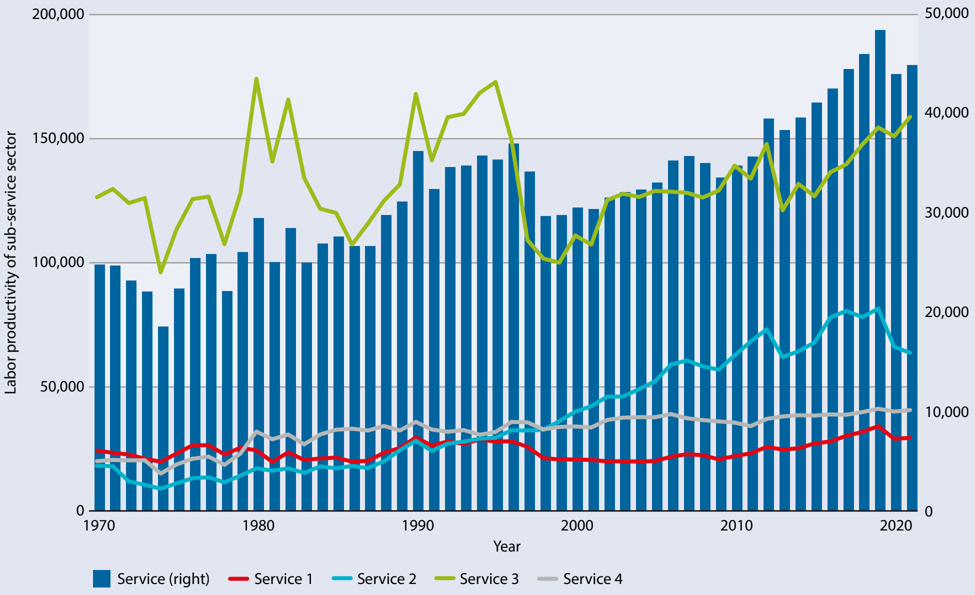
Source: Author's calculations based on the APO Productivity Database

<Service>

- Thailand's service sector productivity has shown a steady growth trend, starting at around 30,000 in the 1970s and reaching over 40,000 by 2020.

- Service Sector 3 (finance, real estate, renting, and business activities) exhibited volatility in labor productivity, fluctuating between 100,000 and 170,000 before stabilizing at approximately 150,000 in recent years.

- The labor productivity of Service 2 (transport and communications) gradually increased over time, while Service 1 (wholesale and retail trade) and Service 4 (community and personal services) remained lower, below 20,000, with each sector experiencing modest growth throughout the period.



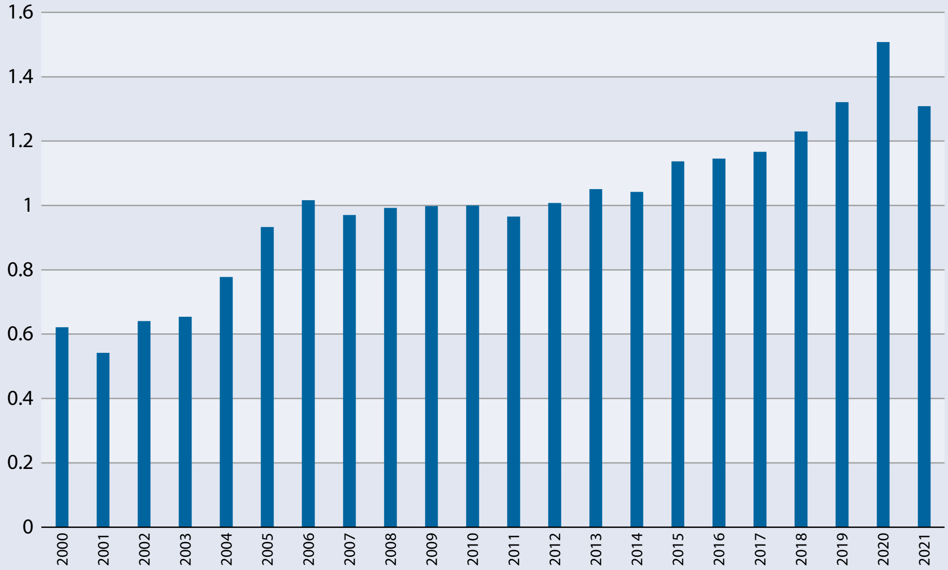
COUNTRY PROFILE: TURKIYE

<Agriculture>

- Turkiye's agricultural labor productivity has gradually increased since the early 2000s. This stable growth trend has persisted through 2021.

FIGURE 1

AGRICULTURAL LABOR PRODUCTIVITY



- Turkiye's Stability remains constant, while Readiness shows minor variations, reflecting steady climate preparedness efforts.

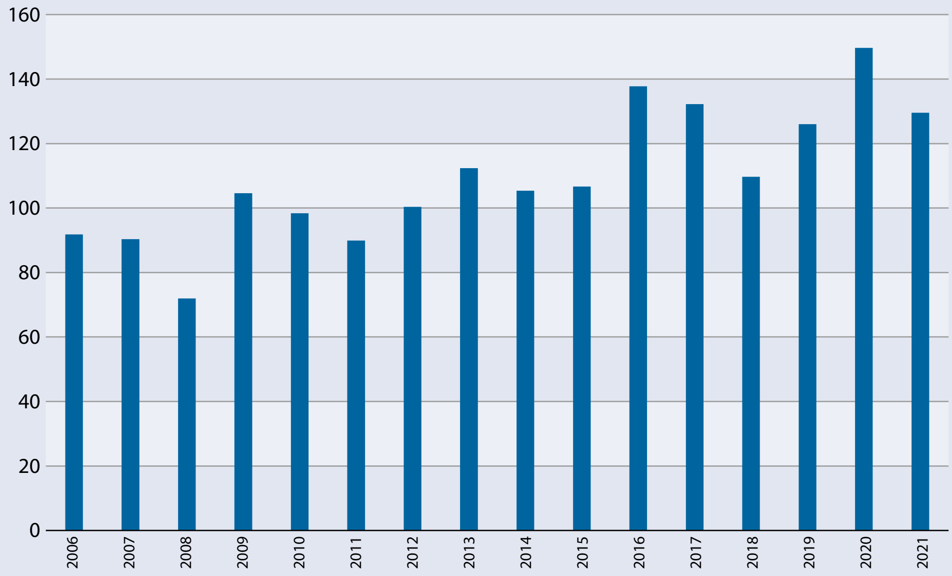
FIGURE 2

CLIMATE CHANGE ADAPTATION: STABILITY, READINESS

- Turkiye's fertilizer consumption has shown slight increases with some fluctuations, maintaining a generally stable trend over time.

FIGURE 3

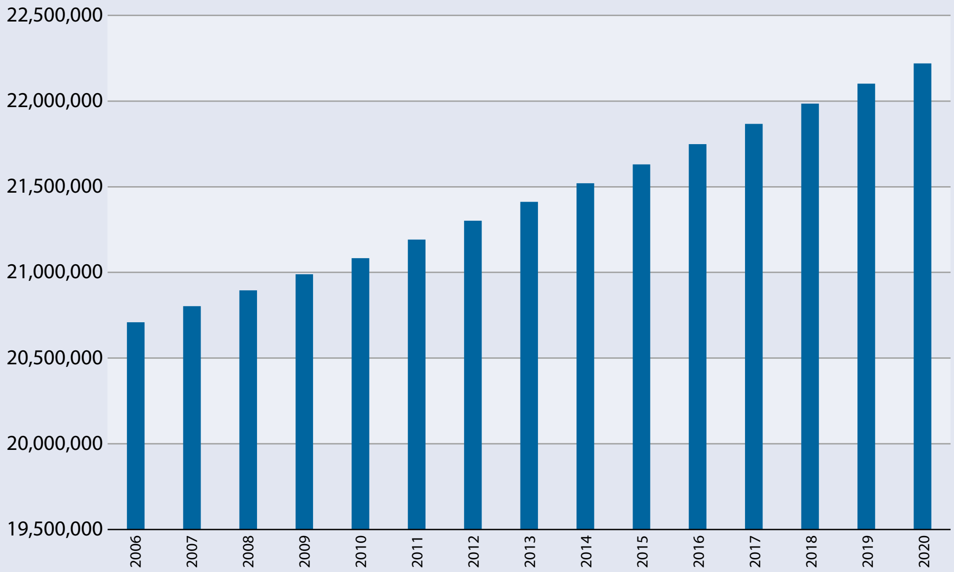
FERTILIZER CONSUMPTION



- Turkiye shows a steady increase in forest area, reflecting ongoing reforestation efforts.

FIGURE 4

FOREST AREA

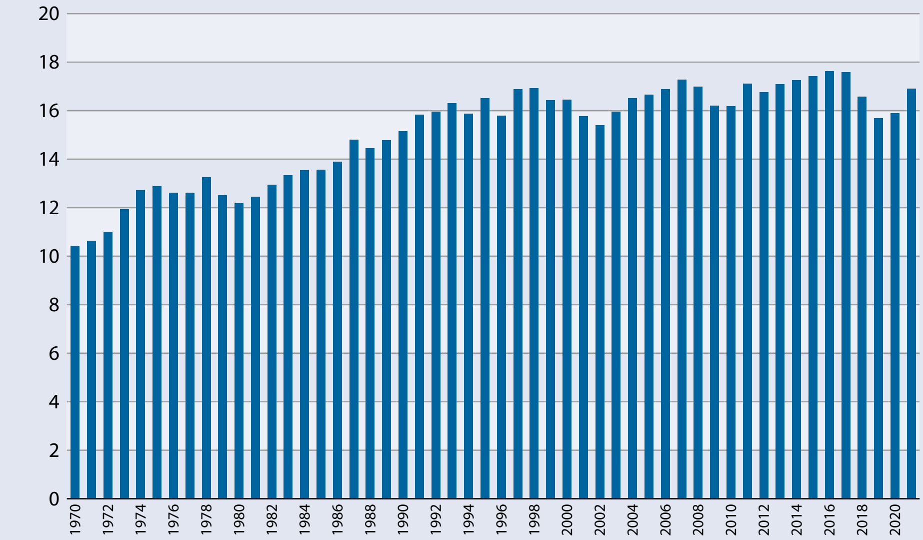


<Manufacturing>

- During the analysis period, there were slight fluctuations, but manufacturing showed a relative increasing trend. It showed a decrease in the early 1980s and early 2000s, and also decreased sharply in 2019 when the COVID-19 pandemic occurred.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP, 1970–2021 (%)

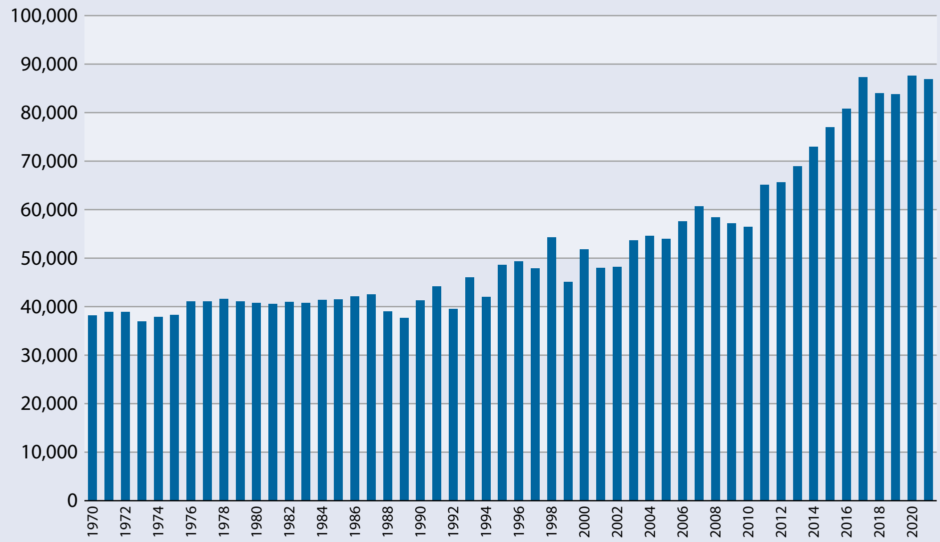


Source: Author's calculations based on the APO Productivity Database

- Unlike the trend in the share of manufacturing in GDP, labor productivity has shown an increasing trend since the 1990s, and particularly increased sharply in the 2010s. This upward trend suggests improvements in efficiency, possibly driven by technology adoption and workforce development.

FIGURE 6

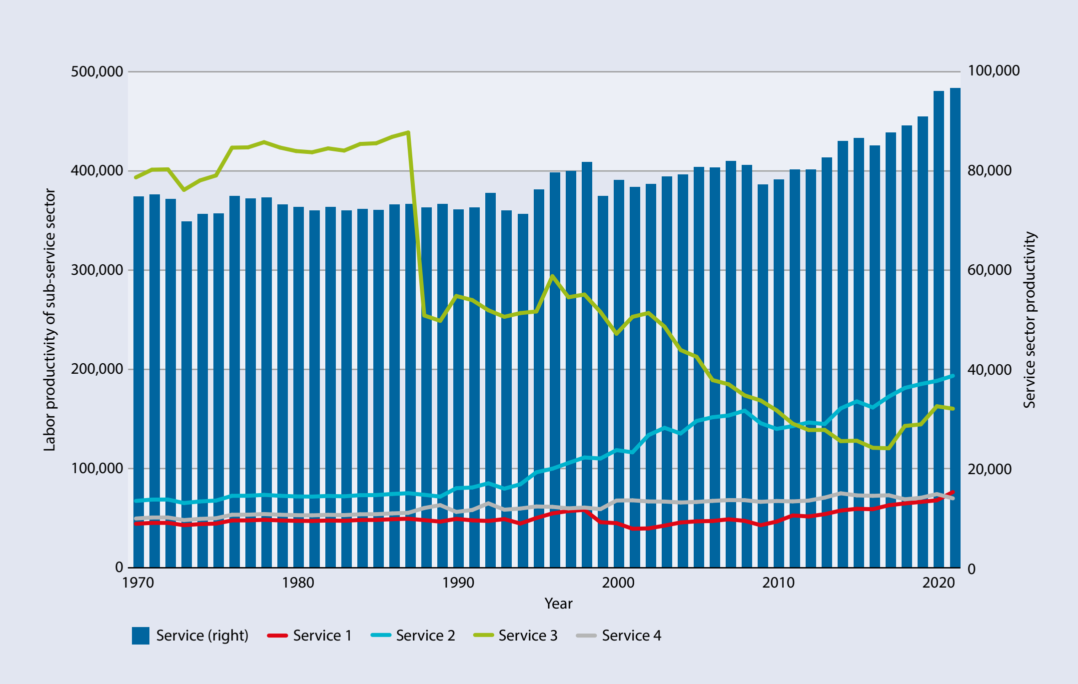
TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR, 1970–2021 (USD)



Source: Author's calculations based on the APO Productivity Database

<Service>

- The service sector productivity in Turkiye has remained relatively stable, with a slight increase in recent years, reaching nearly 100,000 by 2020.
- Service Sector 3 (finance, real estate, renting, and business activities) initially maintained a high labor productivity level but experienced a sharp decline before 1990. In recent decades, it has shown a declining trend and stabilized around 150,000.
- Service 1 (wholesale and retail trade) and Service 4 (community and personal services) remained stable throughout the period, while Service 2 (transport and communications) showed an increasing trend, reaching around 200,000.



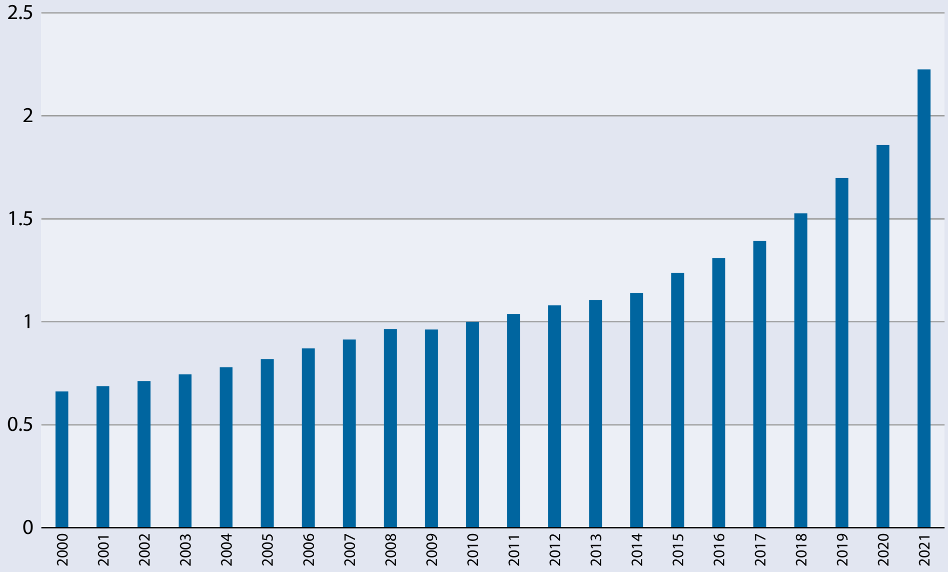
COUNTRY PROFILE: VIETNAM

<Agriculture>

- Vietnam demonstrates a steady upward trend in agricultural labor productivity. Significant improvements have been observed through 2021.

FIGURE 1

AGRICULTURAL LABOR PRODUCTIVITY



- Vietnam displays a consistent trend in both Stability and Readiness, showing a balanced approach to climate change adaptation.

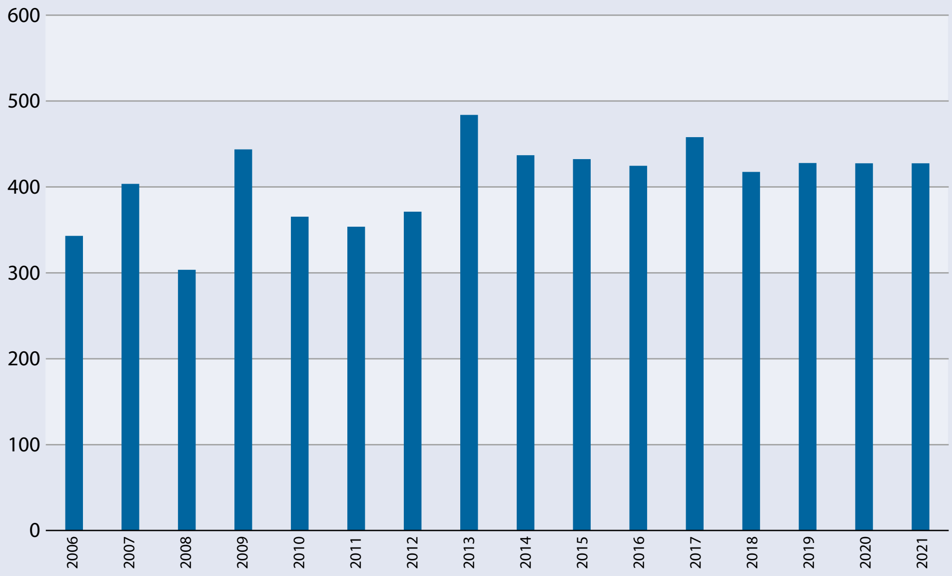
FIGURE 2

CLIMATE CHANGE ADAPTATION: STABILITY, READINESS

- Vietnam demonstrates a stable trend in fertilizer consumption, with some peaks but overall consistency in the level of fertilizer use.

FIGURE 3

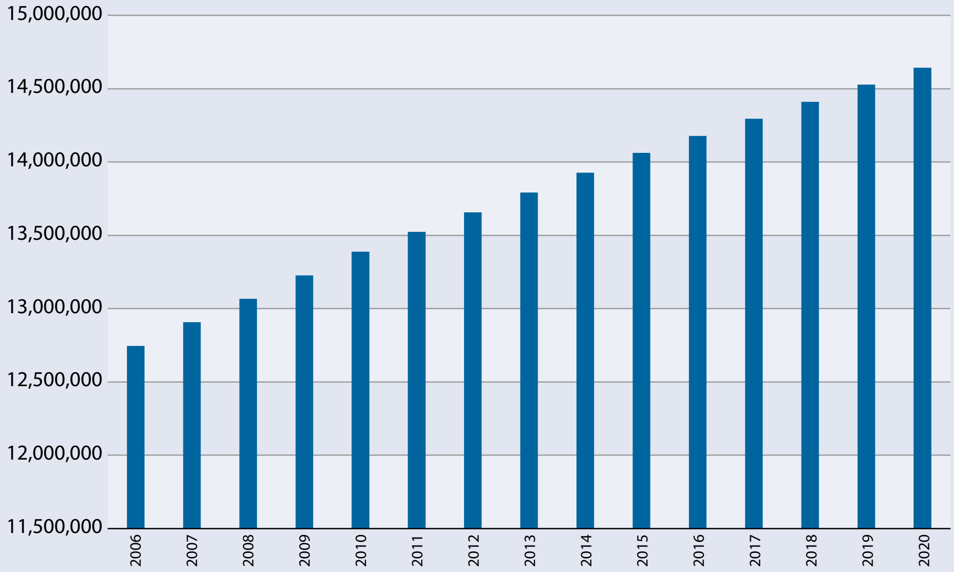
FERTILIZER CONSUMPTION



- Vietnam has shown a steady increase in forest area, with significant growth over the years.

FIGURE 4

FOREST AREA

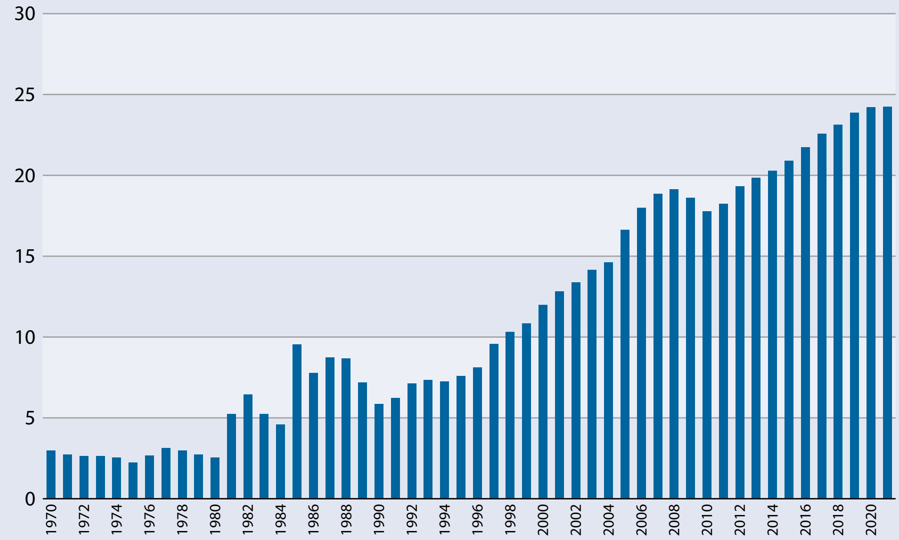


<Manufacturing>

- Manufacturing has shown a sharply increasing trend since the 1990s. Except for the period of the global financial crisis in the late 2000s, it has steadily increased. Growth trend indicates strong industrial growth.

FIGURE 5

TREND OF AVERAGE MANUFACTURING SECTOR'S SHARE IN GDP. 1970–2021 (%)

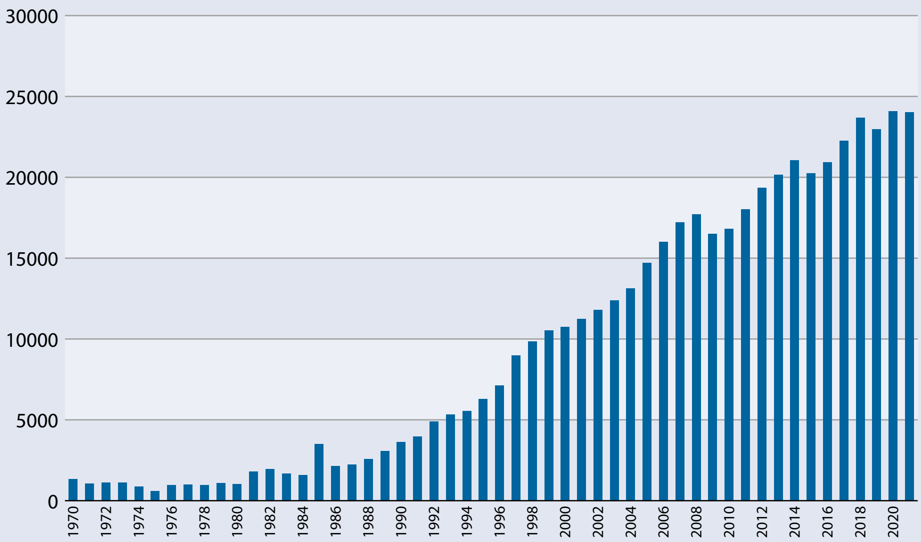


Source: Author's calculations based on the APO Productivity Database

- The trend in labor productivity is very similar to the trend in the share of manufacturing in GDP. Particularly, the sharp increase in the share of manufacturing and labor productivity in the 2010s appears to be due to the benefits of the trade diversion effect following the U.S. trade restrictions against China.

FIGURE 6

TREND OF AVERAGE LABOR PRODUCTIVITY IN MANUFACTURING SECTOR. 1970–2021 (USD)



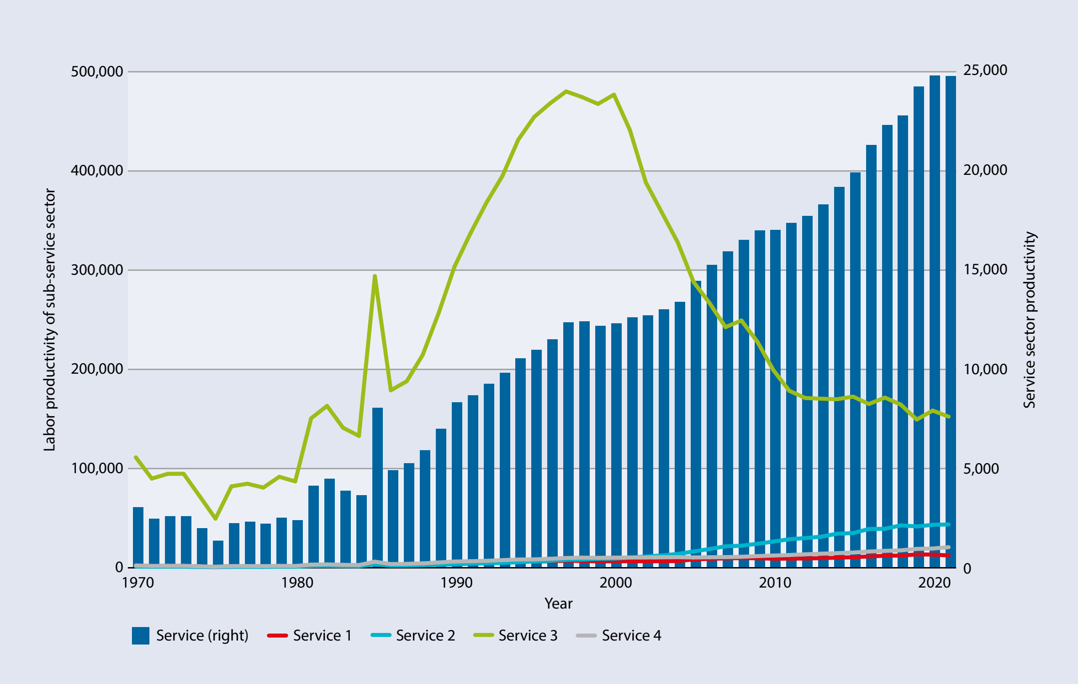
Source: Author's calculations based on the APO Productivity Database

<Service>

- Vietnam's service sector productivity has grown consistently, starting below 5,000 in the early 1970s and reaching over 25,000 by 2020.

- The labor productivity of Service Sector 3 (finance, real estate, renting, and business activities) exhibited a rising trend through the mid-1990s, but transitioned to a steady decline thereafter.

- Other sectors, such as Service 1 (wholesale and retail trade), Service 2 (transport and communications), and Service 4 (community and personal services), exhibited minimal changes in labor productivity overall, with the exception of Service 2, which showed a slight increase in recent years.



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LIST OF CONTRIBUTORS

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Asian Productivity Organization

APO PRODUCTIVITY OUTLOOK 2025

The Impacts of Climate Change on Productivity and Its Policy Implications

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