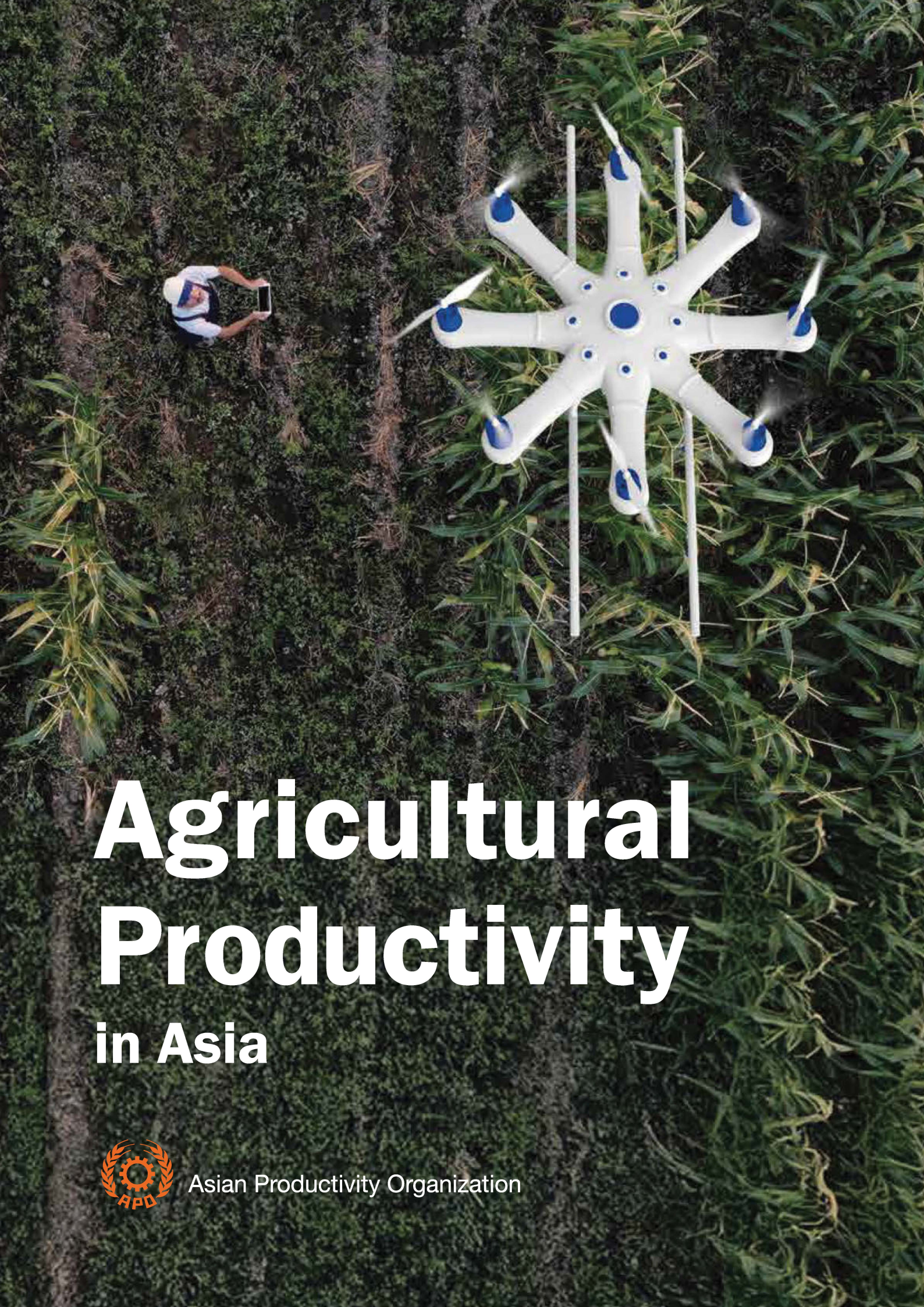

Agricultural Productivity in Asia

Asian Productivity Organization

The Asian Productivity Organization (APO) is an intergovernmental organization that promotes productivity as a key enabler for socioeconomic development and organizational and enterprise growth. It promotes productivity improvement tools, techniques, and methodologies; supports the national productivity organizations of its members; conducts research on productivity trends; and disseminates productivity information, analyses, and data. The APO was established in 1961 and comprises 21 members.

APO Members

Bangladesh, Cambodia, Republic of China, Fiji, Hong Kong, India, Indonesia, Islamic Republic of Iran, Japan, Republic of Korea, Lao PDR, Malaysia, Mongolia, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Turkiye, and Vietnam.

AGRICULTURAL PRODUCTIVITY IN ASIA

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Agricultural Productivity in Asia

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CONTENTS

FOREWORD

Agriculture has long been at the heart of Asia's economic and social progress. It feeds the region, sustains rural livelihoods, and underpins many national economies. This report, Agricultural Productivity in Asia, takes a fresh and detailed look at how productivity has changed over time, the forces shaping it, and the opportunities ahead. Written by Professor Christopher O'Donnell and Associate Professor Antonio Peyrache of the University of Queensland, it combines a clear analytical framework with decades of carefully assembled international data.

Building on an earlier 2019 study by the same authors, which covered 91 countries (1961–2015) and used climate zone proxies for environmental effects, this updated analysis benefits from a richer dataset and improved methods. The study draws on harmonized data from the United States Department of Agriculture, FAO, and WB, covering a 61-year span (1961–2021). In total, 143 countries are examined, including 18 APO members for whom sufficient data are available. The scope is broad: Outputs range fromcrops and livestock to fish and greenhouse gas emissions, while inputs includeland, labor, fertilizer, and capital. By incorporating direct climate indicatorssuch as rainfall and temperature, the analysis better captures climatevariability.

To analyze productivity, the authors apply two complementary techniques: data envelopment analysis and stochastic frontier analysis. The stochastic frontier analysis technique not only gauges performance, but also accounts for statistical noise, an important safeguard when dealing with large, complex datasets. For Asian economies, improvements in output-oriented scale-mix efficiency were the predominant driver of TFP growth, while technical progress played a smaller role; changes in technical efficiency and environmental conditions were comparatively limited.

A key recommendation is the call for stronger, more frequent farm-level data collection. The authors emphasize collaboration with reputable statistical agencies and national statistical offices to refine survey design and improve data quality, including expanded coverage of input–output quantities, better tracking of environmental factors, and systematic documentation of farm management technologies and practices.

In an era marked by climate volatility, demographic shifts, and changing markets, evidence of this depth is invaluable. It is hoped that the insights shared here will

guide APO members in building agricultural systems that are not only more productive, but also more inclusive and resilient.

Dr. Indra Pradana Singawinata
Secretary-General
Asian Productivity Organization
Tokyo

INTRODUCTION

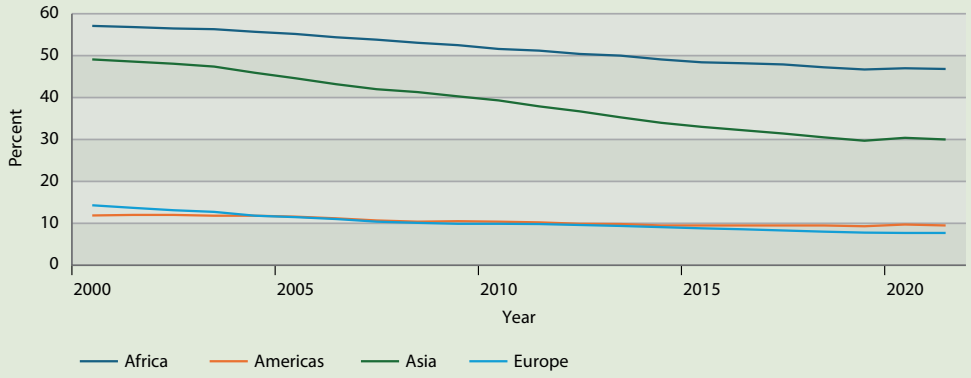
This chapter summarizes the trends in employment and value-added in agriculture worldwide, as well as the current status of agricultural productivity measurement and its analysis. The tables and figures used to illustrate the productivity trends in Asian Productivity Organization (APO) economies and other benchmark countries are the authors' own work.

Trends in the Performance of the Agriculture Sector

According to ILO estimates, the agriculture sector employed 39.8% of the world's labor force in 2000; however, by 2021, this percentage had fallen to 26.6% (ILO, 2025). Figure 1 reports a breakdown of this change by year and region. It also indicates that the agriculture sectors in Africa and Asia have always employed a much larger percentage of the labor force than those in the Americas and Europe; that is, in 2000 (2021), the agriculture sector employed 57.1% (46.8%) of the labor force in Africa, 49.1% (30.0%) in Asia, 11.9% (9.5%) in the Americas, and 14.3% (7.7%) in Europe (ILO, 2025). These regional differences in employment ratios are also generally associated with regional differences in national incomes; specifically, low agricultural employment ratios are generally associated with higher national incomes. To illustrate this point, Table 1 presents a breakdown of the agricultural employment ratios in 2021, both worldwide and in Asia, by national income category (and sex). The table reveals that, in 2021, the agriculture sector in low (high) income countries employed 58.0% (3.3%) of the world's labor force; further, in 2021, the agriculture sector in low (high) income Asian countries employed 47.1% (3.5%) of the region's labor force (ILO, 2025).

FIGURE 1

AGRICULTURAL EMPLOYMENT AS A PERCENTAGE OF THE TOTAL LABOR FORCE, 2000–21



Source: Authors' illustration based on ILO (2025).

TABLE 1

AGRICULTURAL EMPLOYMENT AS A PERCENTAGE OF THE TOTAL LABOR FORCE, 2021

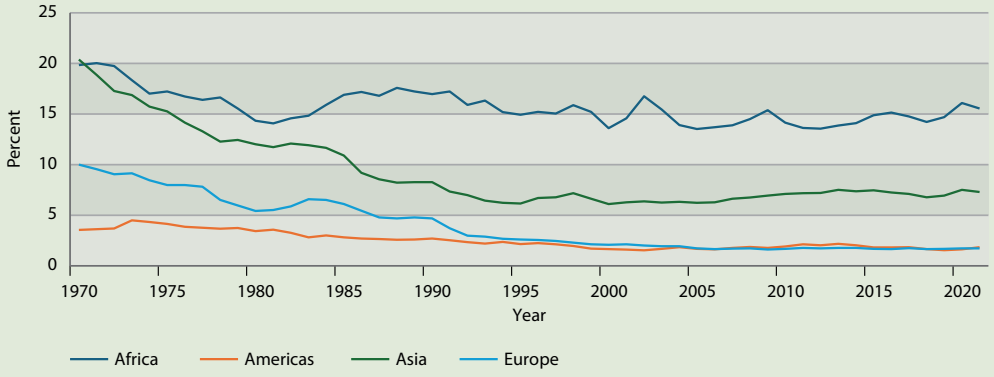
Region/Country	Total	Female	Male
World: Low income	58.0	62.2	54.9
World: Lower-middle income	39.9	46.6	36.6
World: Upper-middle income	21.6	18.3	24.0
World: High income	3.3	2.3	4.2
Asia and the Pacific: Low income	47.1	53.6	43.1
Asia and the Pacific: Lower-middle income	40.8	51.7	36.3
Asia and the Pacific: Upper-middle income	24.1	20.6	26.8
Asia and the Pacific: High income	3.5	2.8	4.1

Source: ILO (2025).

According to FAO estimates, the agriculture sector accounted for 9.4% of world GDP in 1970; by 2021, this percentage had fallen to 4.3% FAO (2025a). Figure 2 reports a breakdown of this change by year and region. Notably, the agriculture sectors in Africa and Asia have accounted for a much larger proportion of regional GDP than those in the Americas and Europe for many years; for instance, in 1970 (2021), the agriculture sector in Africa accounted for 19.8% (15.5%) of the region's GDP, while it accounted for 20.4% (7.3%) in Asia, 3.6% (1.8%) in the Americas, and 10.0% (1.7%) in Europe (FAO, 2025a).

FIGURE 2

AGRICULTURAL GDP AS A PERCENTAGE OF THE TOTAL GDP, 1970–2021



Source: Authors' illustration based on FAO (2025a).

Current Status of Agricultural Productivity Measurement

The measurement of agricultural productivity typically involves the computation of partial factor productivity (PFP) and/or TFP measures. On the one hand, a PFP measure is defined as the volume (i.e., quantity) of outputs divided by the volume of a single input. PFP measures widely used in agriculture include output per hectare (i.e., land productivity), output per person (i.e., labor productivity), and output per unit of physical capital (i.e., capital productivity). For instance, Kumbhakar (1996) used farm-level data to analyze labor productivity in India from 1980 to 1985,

and Holden et al. (2009) used farm-plot-level data to analyze land productivity in Ethiopia from 1998 to 2006.

On the other hand, a TFP measure is defined as the volume of outputs divided by a volume measure of *all* inputs. TFP measures widely used in agriculture include the Fisher, Törnqvist, Malmquist, Hicks-Moorsteen (HM), Elteto-Koves-Szulc, and Caves-Christensen-Diewert TFP indices. For example, Mullen (2007) used farm-level data and the Fisher TFP index (TFPI) to measure agricultural productivity changes in Australia from 1954 to 2004, Coelli and Rao (2005) used FAO data and the Malmquist index to measure agricultural productivity changes in 93 countries from 1980 to 2000, and Hadley et al. (2013) used farm-level data and the HM index to measure agricultural productivity changes in England and Wales from 2000 to 2004.

Unfortunately, except in restrictive special cases (e.g., when there is only one output and one input), the TFP indices described above do not satisfy common notions (or axioms) from index theory. For example, the Fisher, Törnqvist, Malmquist, and HM TFP indices do not satisfy the transitivity axiom. For example, if farmer A is twice as productive as farmer B, and farmer B is twice as productive as farmer C, then a transitive TFPI will say that farmer A is four times as productive as farmer C. However, the Fisher, Törnqvist, Malmquist, and HM TFP indices will generally say something else. TFP indices with good axiomatic properties include the Lowe and geometric Young (GY) TFP indices. Both have been used in the context of agriculture. For example, O'Donnell (2012) used United States Department of Agriculture (USDA) data and the Lowe index to measure agricultural productivity change in 48 states from 1960 to 2004, while O'Donnell (2016) used USDA data and the GY index to measure agricultural productivity change in 11 states from 1960 to 1989.

Current Explanations for Agricultural Productivity Change

Measures of productivity change are derived by dividing measures of output change by measures of input change. Economists use many different models to explain output and input changes (and, thus, productivity changes). For example, it is common for business economists to assume that firms are price takers in output and input markets, and that businesspersons choose outputs and inputs to maximize profits. In such cases, profit-maximizing output and input quantities will change with (a) relative output and input prices (i.e., the terms of trade) and (b) the characteristics of the "production possibilities set" (i.e., the set of output–input combinations that are technically possible). It is also common for agricultural economists to assume that (a) firms are price takers in output and input markets, and (b) farmers choose inputs to maximize their expected profits in the face of uncertainty about output prices and the characteristics of the production environment (e.g., rainfall). In these cases, the inputs that maximize expected revenue (and, ultimately, realized outputs) will change with (a) input prices, (b) expectations about output prices, (c) environmental variables, and (d) the characteristics of the production possibilities set. However, more complex models of firm behavior are also available. In most, if not all, of these models, output and input changes (and, thus, productivity changes) depend, *inter alia*, on the characteristics of the production possibilities set. Different explanations for output and input changes (and productivity changes) generally involve different assumptions about this set. For example, Kumbhakar (1996) assumed that the boundary of the production possibilities set (i.e., the "production frontier") can be represented by a translog function, while Coelli and Rao (2005) considered that the production frontier exhibits constant returns to scale (CRS).

In practice, firms' *observed* outputs and inputs may differ from their *optimal* outputs and inputs because firm managers do not have enough knowledge and/or skills to solve complex maximization problems (i.e., they are "boundedly rational"). The failure to solve optimization problems is known as inefficiency (e.g., the difference between observed profit and the maximum possible profit is known as profit inefficiency). Different explanations for output and input changes (and, thus, productivity changes) allow for different types of inefficiency. For example, Coelli and Rao (2005) allowed for output-oriented technical inefficiency (i.e., the failure to produce the maximum output from given inputs).

PRODUCTIVITY CONCEPTS AND ANALYTICAL METHODS

This chapter provides a brief overview of the main concepts and methods used in this report to analyze TFP changes. It draws on O'Donnell (2016) and O'Donnell (2018).

Production Technologies

In O'Donnell (2016, 2018), a "production technology" (or simply "technology") refers to a technique, method, or system for transforming inputs into outputs (e.g., a technique for planting and growing rice). For practical purposes, O'Donnell (2016) found it convenient to think of a technology as a book of instructions or a recipe. A set of technologies in any given period is called a "technology set." If we think of a technology as a book of instructions, then we can think of a technology set as a library.

Common Assumptions

It is possible to *measure* TFP change without knowing anything about technologies (i.e., we can calculate changes in output–input ratios without knowing anything about how the inputs are used to produce the outputs). However, we generally need to make some assumptions about technologies to *explain* productivity changes. As such, it is common to assume the following:

A1: It is possible to produce zero output.

A2: There is a limit to what can be produced using a finite amount of inputs.

A3: A positive amount of at least one input is needed to produce a positive amount of any output.

A4: The set of outputs that can be produced using given inputs contains all points on its boundary.

A5: The set of inputs that can produce given outputs contains all points on its boundary.

A6: If given inputs can be used to produce particular outputs, then they can also be used to produce fewer outputs (outputs are strongly disposable).

A7: If given outputs can be produced using particular inputs, then they can also be produced using more inputs (inputs are strongly disposable).

A8: If a given output–input combination is possible in a particular production environment, then it is also possible in a better production environment (environmental variables are strongly disposable).

A9: If two input–output combinations are possible, then any linear combination of those input–output combinations is also possible (production possibility sets are convex).

This report is based on the abovementioned assumptions. If they hold true, then technologies can be represented using various sets and functions; the focus of this report is on output sets and output distance functions (ODFs).

Output Sets

An output set is a set containing all outputs that can be produced using given inputs. A *period-and-environment-specific* output set is a set containing all outputs that can be produced using given inputs *in a given period and within a given production environment*. As a precise definition, let $x = (x_1, \ldots, x_M)'$, $q = (q_1, \ldots, q_N)'$, and $z = (z_1, \ldots, z_J)'$ denote vectors of inputs, outputs, and environmental variables, respectively. Mathematically, the set of outputs that can be produced using inputs x in period t (i.e., using the period-t technology set) in an environment characterized by z is

$$P^t(x, z) = \{q : x \text{ can produce } q \text{ in period } t \text{ in environment } z\}. \tag{2.1}$$

The boundary of this set is a period-and-environment-specific frontier. A considerable part of productivity and efficiency analyses is concerned with estimating how the position and shape of this frontier changes over time. An example of an output set is

$$P^t(x, z) = \left\{ \sum_{n=1}^{N} \gamma_n q_n \leq A(t) \prod_{j=1}^{J} z_j^{\delta_j} \prod_{m=1}^{M} x_m^{\beta_m} \right\}, \tag{2.2}$$

where $A(t) > 0$ is a measure of how the production frontier changes over time, $\beta = (\beta_1, \ldots, \beta_M)' \geq 0$ is a vector of output elasticities, $\gamma = (\gamma_1, \ldots, \gamma_N)' \geq 0$ is a vector of parameters that sum to one, and $\sum_m \beta_m = r$ is the elasticity of scale. The elasticity of scale measures the percentage increase in the output vector resulting from a 1% increase in the input vector, holding all other variables fixed. The production frontier is said to exhibit decreasing returns to scale, CRS, or increasing returns to scale when the elasticity of scale is less than, equal to, or greater than 1, respectively.

ODFs

An ODF gives the reciprocal of the largest factor by which it is possible to scale up a given output vector when using a given input vector. For example, if it is technically possible for a firm to use its inputs to produce five times the amount of every output, the ODF takes the value $\rho = 1/5 = 0.2$. A *period-and-environment-specific* ODF gives the reciprocal of the largest factor by which it is possible to scale up a given output vector when using a given input vector *in a given period and within a given production environment*. Mathematically, the reciprocal of the largest factor by which it is possible to scale up output vector q when using inputs x in period t in an environment characterized by z is

$$D_O^t(x, q, z) = \inf\{\rho > 0 : q/\rho \in P^t(x, z)\}. \tag{2.3}$$

ODFs are non-negative and linearly homogeneous in outputs. If outputs are strongly disposable, they are also non-decreasing in outputs. If assumptions A2 and A6–A8 hold true, then output sets and ODFs are equivalent representations of technologies. For example, if the output set is given by (2.2), the ODF is

$$D_O^t(x, q, z) = \left\{ \sum_{n=1}^{N} \gamma_n q_n \leq A(t) \prod_{j=1}^{J} z_j^{\delta_j} \prod_{m=1}^{M} x_m^{\beta_m} \right\}, \tag{2.4}$$

where $A(t) > 0$, $\beta = (\beta_1, \ldots, \beta_M)' \geq 0$, $\gamma = (\gamma_1, \ldots, \gamma_N)' \geq 0$, and $\sum_n \gamma_n = 1$.

Managerial Behavior

The existence of different sets and functions has no implications for managerial behavior. For instance, the existence of the ODF does not mean that managers will attempt to scale up their output vectors until they reach the production frontier. Rather, they will tend to behave differently, depending on what they value and what they can or cannot choose. This report focuses on the managers who seek to maximize output and/or TFP. At this point, it is convenient to add firm and time subscripts to the different variables; for example, it is convenient to let $x_{it} = (x_{1it}, \ldots, x_{Mit})'$ and $q_{it} = (q_{1it}, \ldots, q_{Nit})'$ denote the outputs and inputs of firm i in period t, respectively.

Output Maximization

If a firm manager places non-negative values on outputs (not necessarily market values), and all other variables involved in the production process are predetermined, they will generally aim to maximize a measure of total output. If there is more than one output, the precise form of the output maximization problem will depend on how easily the manager can choose the output mix. If the manager of firm i can only choose output vectors that are scalar multiples of $q_{it} \geq 0$, then the period-t output-maximization problem is

$$\max_q \{Q(q) : q \propto q_{it},\ D_O^t(x_{it}, q, z_{it}) \leq 1\}, \tag{2.5}$$

where $Q(.)$ is a non-negative, non-decreasing, linearly homogeneous scalar-valued aggregator function, satisfying $Q(q_{it}) > 0$. The output vector that solves this problem is $\bar{q}_{it} \equiv q_{it} / D_O^t(x_{it}, q_{it}, z_{it})$, which lies on the production frontier. The associated aggregate output is

$$Q(\bar{q}_{it}) = Q(q_{it}) / D_O^t(x_{it}, q_{it}, z_{it}). \tag{2.6}$$

TFP Maximization

If a firm's manager places non-negative values on outputs and inputs and all environmental variables are predetermined, they may aim to maximize a measure of TFP. TFP is a volume (i.e., quantity) measure, defined as the ratio of a quantity measure of total output to a quantity measure of total input. If the manager of firm i can choose outputs and inputs freely, then the period-t TFP-maximization problem can be written as

$$\max_{x \geq 0, q \geq 0} \{Q(q) / X(x) : D_O^t(x, q, z_{it}) \leq 1\}, \tag{2.7}$$

where $Q(.)$ and $X(.)$ are non-negative, non-decreasing, linearly homogeneous scalar-valued aggregator functions with parameters (or weights) that represent the values that the firm manager places on outputs and inputs. There may be several pairs of output and input vectors that solve this problem. Let q_{it}^{*} and x_{it}^{*} denote such a pair. This output–input combination lies on the production frontier. The associated maximum TFP is

$$TFP^{t}\left(z_{it}\right)=Q\left(q_{it}^{*}\right)\Big/X\left(x_{it}^{*}\right). \tag{2.8}$$

Measures of Efficiency

Measures of efficiency can be viewed as measures of how well firm managers solve different optimization problems. This report focuses on output–oriented measures of technical and scale-mix efficiency (TSME). These measures take values between 0 (totally inefficient) and 1 (fully efficient).

Output-Oriented Technical Efficiency (OTE)

The OTE of manager i in period t can be viewed as a measure of how well the manager has solved problem (2.5). Mathematically, the OTE of manager i in period t is

$$OTE^{t}\left(x_{it},q_{it},z_{it}\right)=Q\left(q_{it}\right)/Q\left(\bar{q}_{it}\right), \tag{2.9}$$

where $Q(q_{it})$ is the aggregate output of the firm and $Q(\bar{q}_{it})=Q(q_{it})\big/D_{O}^{t}(x_{it},q_{it},z_{it})$ is the maximum aggregate output possible when using x_{it} to produce a scalar multiple of q_{it} in period t in an environment characterized by z_{it}. The following is an equivalent definition (O'Donnell, 2016, p. 331):

$$OTE^{t}\left(x_{it},q_{it},z_{it}\right)=D_{O}^{t}\left(x_{it},q_{it},z_{it}\right). \tag{2.10}$$

This concept can be traced back to at least Farrell (1957). A manager may be technically inefficient because they did not choose the right technology (i.e., did not choose the right "book from the library") and/or did not use the chosen technology properly (i.e., did not "follow instructions").

TSME

The TSME of manager i in period t can be considered as a measure of how well they solved problem (2.7). Mathematically, the TSME of manager i in period t is

$$TSME^{t}\left(x_{it},q_{it},z_{it}\right)=TFP\left(x_{it},q_{it}\right)\Big/TFP^{t}\left(z_{it}\right), \tag{2.11}$$

where $TFP\left(x_{it},q_{it}\right)=Q(q_{it})\big/X(x_{it})$ is the observed TFP of the firm, and $TFP^{t}\left(z_{it}\right)=Q(q_{it}^{*})\big/X(x_{it}^{*})$ is the maximum TFP possible in period t in an environment characterized by z_{it}. The concept of TSME is equivalent to the concept of "firm efficiency" as defined by O'Donnell (2016, p. 331). More importantly, the TSME of a firm can be decomposed into output-oriented measures of technical efficiency and scale-mix efficiency. The technical efficiency component is the measure of OTE defined in (2.9). The associated output-oriented scale-mix efficiency (OSME) of manager i in period t is

$$OSME^{t}\left(x_{it},q_{it},z_{it}\right)=TFP\left(x_{it},\bar{q}_{it}\right)\Big/TFP^{t}\left(z_{it}\right), \tag{2.12}$$

where $TFP(x_{it}, \bar{q}_{it}) = Q(\bar{q}_{it})/X(x_{it})$ is the maximum TFP possible when using x_{it} to produce a scalar multiple of q_{it} in period t in an environment characterized by z_{it}. Equivalently,

$$OSME^t(x_{it}, q_{it}, z_{it}) = TSME^t(x_{it}, q_{it}, z_{it}) / OTE^t(x_{it}, q_{it}, z_{it}). \quad (2.13)$$

Therefore, OSME can be viewed as the component of TSME that remains after accounting for OTE. This concept can be traced back to at least O'Donnell (2012, p. 881).

Index Numbers

An index is a measure of change in a variable (or group of variables) over time and/or space. A TFPI is an output index divided by an input index. This report is concerned with output and input indices that are "proper" in that they satisfy the common notions or axioms of O'Donnell (2016).

Output Indices

In O'Donnell (2016), an output quantity index that compares q_{it} with q_{ks} using the latter as the reference (or base) vector is defined as any variable of the form

$$QI(q_{ks}, q_{it}) = Q(q_{it})/Q(q_{ks}), \quad (2.14)$$

where $Q(.)$ is any non-negative, non-decreasing, linearly homogeneous scalar-valued aggregator function. Output indices constructed in this way are "proper" in that they satisfy the index number axioms of O'Donnell (2016, p. 332). One of these axioms is transitivity. If, for example, firm A produces twice as much as firm B, and firm B produces twice as much as firm C, a transitive output index will say that firm A produces four times as much as firm C. Any non-negative, non-decreasing, linearly homogeneous scalar-valued aggregator function can be used to construct a proper output index. This report uses an additive index. Additive indices are constructed using aggregator functions of the form $Q(q_{it}) \propto a'q_{it}$, where a is any non-negative vector of weights. The class of additive output indices includes the Lowe output index of O'Donnell (2012, p. 877).

Input Indices

In O'Donnell (2016), an input quantity index that compares x_{it} with x_{ks} using the latter as the reference vector is defined as any variable of the form

$$XI(x_{ks}, x_{it}) = X(x_{it})/X(x_{ks}), \quad (2.15)$$

where $X(.)$ is a non-negative, non-decreasing, linearly homogeneous scalar-valued aggregator function. Again, all input indices constructed in this way are "proper" in that they satisfy the index number axioms of O'Donnell (2016, p. 332). This report uses an additive index. Additive input indices are constructed using aggregator functions of the form $X(x_{it}) \propto b'x_{it}$, where b is any non-negative vector of weights. The class of additive input indices includes the Lowe input index of O'Donnell (2012, p. 877).

TFP Indices

In O'Donnell (2016), an index that compares the TFP of firm i in period t with that of firm k in period s is any variable of the following form:

$$TFPI\left(x_{ks}, q_{ks}, x_{it}, q_{it}\right) = QI\left(q_{ks}, q_{it}\right) / XI\left(x_{ks}, x_{it}\right), \tag{2.16}$$

where $QI(.)$ is any proper output index, and $XI(.)$ is any proper input index. In O'Donnell (2016), a TFPI is said to be "proper" if and only if it can be written in this form. The class of proper TFP indices includes the Lowe TFPI of O'Donnell (2012) and the GY TFPI of O'Donnell (2016).

Data Envelopment Analysis (DEA)

Productivity analysis involves estimating production frontiers. DEA methods used for estimating production frontiers can be traced back to at least Farrell (1957). The most common DEA models are underpinned by the following assumptions:

DEA1: All relevant quantities, prices, and/or environmental variables are observed and measured without error.

DEA2: Production frontiers are piecewise (or locally) linear.

DEA3: Outputs, inputs, and environmental variables are strongly disposable.

DEA4: Production possibility sets are convex.

Under these assumptions, most efficiency measures can be estimated by solving linear programs (LPs).

Estimating OTE

Estimating the measure of OTE defined by (2.9) involves estimating the ODF. If assumptions DEA1 and DEA2 hold true, the ODF is given by

$$D_O^{it}\left(x_{it}, q_{it}, z_{it}\right) = \gamma_{it}' q_{it} / \left(\alpha_{it} + \delta_{it}' z_{it} + \beta_{it}' x_{it}\right), \tag{2.17}$$

where γ_{it}, α_{it}, δ_{it}, and β_{it} are the unknown parameters to be estimated. Estimating these parameters involves maximizing $\gamma_{it}' q_{it} / (\alpha_{it} + \delta_{it}' z_{it} + \beta_{it}' x_{it})$, subject to constraints that ensure assumptions DEA3 and DEA4 are satisfied. Assumption DEA3 will be satisfied if and only if $\gamma_{it} \geq 0$, $\delta_{it} \geq 0$, and $\beta_{it} \geq 0$. If there are I firms in the dataset, assumption DEA4 will be satisfied if and only if $\gamma_{it}' q_{hr} \leq \alpha_{it} + \delta_{it}' z_{hr} + \beta_{it}' x_{hr}$ for all $h \leq I$ and $r \leq t$. For identification purposes, it is common to set $\gamma_{it}' q_{it} = 1$. Under these constraints, the estimation problem becomes

$$\begin{aligned} \min_{\alpha_{it}, \delta_{it}, \beta_{it}, \gamma_{it}} \; & \{\alpha_{it} + \delta_{it}' z_{it} + \beta_{it}' x_{it} : \gamma_{it} \geq 0, \delta_{it} \geq 0, \beta_{it} \geq 0, \\ & \gamma_{it}' q_{hr} \leq \alpha_{it} + \delta_{it}' z_{hr} + \beta_{it}' x_{hr} \text{ for all } h \leq I \\ & \text{and } r \leq t, \gamma_{it}' q_{it} = 1\}. \end{aligned} \tag{2.18}$$

This is a standard LP. The value of the objective function at the optimum is an estimate of the reciprocal of $OTE^t(x_{it}, q_{it}, z_{it})$. Problem (2.18) can also be found in O'Donnell et al. (2017, Eq. 18).

Problem (2.18) is a "primal" LP. Every primal LP has a dual form, with the property that if both the primal and its dual have feasible solutions, then the optimized values of the two objective functions are equal. The dual form of (2.18) is as follows:

$$\max_{\mu,\lambda_{11},\ldots,\lambda_{It}} \left\{ \mu : \mu q_{it} \le \sum_{h=1}^{I}\sum_{r=1}^{t} \lambda_{hr} q_{hr}, \right.$$
$$\sum_{h=1}^{I}\sum_{r=1}^{t} \lambda_{hr} z_{hr} \le z_{it}, \sum_{h=1}^{I}\sum_{r=1}^{t} \lambda_{hr} x_{hr} \le x_{it}, \tag{2.19}$$
$$\left. \sum_{h=1}^{I}\sum_{r=1}^{t} \lambda_{hr} = 1, \quad (\lambda_{11}, \ldots, \lambda_{It})' \ge 0 \right\}.$$

Again, this is a standard LP. Furthermore, the value of the objective function at the optimum is an estimate of the reciprocal of $OTE^t(x_{it}, q_{it}, z_{it})$. Problem (2.19) can also be found in O'Donnell et al. (2017, Eq. 19).

Estimating TSME

Estimating the measure of TSME defined by (2.11) involves estimating the maximum TFP possible in a given period and within a given production environment. Thus, the estimation problem can be written as

$$\max_{q,x,\lambda_{11},\ldots,\lambda_{It}} \left\{ Q(q)/X(x) : q \le \sum_{h=1}^{I}\sum_{r=1}^{t} \lambda_{hr} q_{hr}, \right.$$
$$\sum_{h=1}^{I}\sum_{r=1}^{t} \lambda_{hr} z_{hr} \le z_{it}, \sum_{h=1}^{I}\sum_{r=1}^{t} \lambda_{hr} x_{hr} \le x, \tag{2.20}$$
$$\left. \sum_{h=1}^{I}\sum_{r=1}^{t} \lambda_{hr} = 1, \quad (\lambda_{11}, \ldots, \lambda_{It})' \ge 0 \right\}.$$

This is a fractional program. The value of the objective function at the optimum is an estimate of $TFP^t(z_{it})$. The problem can also be written as

$$\max_{\bar{q},\bar{x},\theta_{11},\ldots,\theta_{It}} \left\{ Q(\bar{q}) : \bar{q} \le \sum_{h=1}^{I}\sum_{r=1}^{t} \theta_{hr} q_{hr}, \; X(\bar{x}) = 1, \right.$$
$$\sum_{h=1}^{I}\sum_{r=1}^{t} \theta_{hr} z_{hr} \le \kappa z_{it}, \sum_{h=1}^{I}\sum_{r=1}^{t} \theta_{hr} x_{hr} \le \bar{x}, \tag{2.21}$$
$$\left. \sum_{h=1}^{I}\sum_{r=1}^{t} \theta_{hr} = \kappa, (\theta_{11}, \ldots, \theta_{It})' \ge 0 \right\}.$$

The value of the objective function at the optimum is still an estimate of $TFP^t(z_{it})$, the value of κ at the optimum is an estimate of $1/X(x_{it}^*)$, and the values of $\bar{q}$ and $\bar{x}$ at the optimum are estimates of $q_{it}^*/X(x_{it}^*)$ and $x_{it}^*/X(x_{it}^*)$, respectively. If the aggregator functions are linear functions, as they are in this project, then (2.21) is an LP.

Decomposing TFP Change

DEA methods can be used to decompose any proper TFPI into a measure of environment and technical change (ETC) and a measure of TSME change (TSMEC). Mathematically,

$$TFPI\left(x_{ks}, q_{ks}, x_{it}, q_{it}\right) = \left[\frac{TFP^{t}\left(z_{it}\right)}{TFP^{s}\left(z_{ks}\right)}\right]\left[\frac{TSME^{t}\left(x_{it}, q_{it}, z_{it}\right)}{TSME^{s}\left(x_{ks}, q_{ks}, z_{ks}\right)}\right], \tag{2.22}$$

where $TFP^{t}(z_{it})$ is the maximum TFP possible in period t in an environment characterized by z_{it}, and $TSME^{t}(x_{it}, q_{it}, z_{it})$ is the measure of TSME defined by (2.11). The first ratio on the right-hand side of (2.22) represents ETC while the second represents TSMEC. These two ratios can be broken into even smaller components. First, the ETC measure can be divided into local measures of environmental change (EC) and technical change (TC). Mathematically,

$$\frac{TFP^{t}\left(z_{it}\right)}{TFP^{s}\left(z_{ks}\right)} = \left[\frac{TFP^{t}\left(z_{it}\right)}{TFP^{t}\left(z_{ks}\right)}\frac{TFP^{s}\left(z_{it}\right)}{TFP^{s}\left(z_{ks}\right)}\right]^{1/2}\left[\frac{TFP^{t}\left(z_{it}\right)}{TFP^{s}\left(z_{it}\right)}\frac{TFP^{t}\left(z_{ks}\right)}{TFP^{s}\left(z_{ks}\right)}\right]^{1/2}. \tag{2.23}$$

The first ratio on the right-hand side of (2.23) represents EC and the second represents TC. Second, the TSMEC measure in (2.22) can be divided into separate measures of technical efficiency change and scale-mix efficiency change. Mathematically,

$$\frac{TSME^{t}\left(x_{it}, q_{it}, z_{it}\right)}{TSME^{s}\left(x_{ks}, q_{ks}, z_{ks}\right)} = \left[\frac{OSME^{t}\left(x_{it}, q_{it}, z_{it}\right)}{OSME^{s}\left(x_{ks}, q_{ks}, z_{ks}\right)}\right]\left[\frac{OTE^{t}\left(x_{it}, q_{it}, z_{it}\right)}{OTE^{s}\left(x_{ks}, q_{ks}, z_{ks}\right)}\right]. \tag{2.24}$$

The first ratio on the right-hand side of (2.24) represents OSME change (OSMEC), and the second represents OTE change (OTEC).

In summary, DEA methods can be used to decompose any TFPI into the product of EC, TC, OSMEC, and OTEC (i.e., TFPI = EC × TC × OSMEC × OTEC).

Stochastic Frontier Analysis (SFA)

SFA methods for estimating production frontiers can be traced back to Aigner et al. (1977) and Meeusen and van den Broeck (1977). Stochastic frontier models (SFMs) account for the possibility that some variables involved in the production process are unobserved or measured with error; they also recognize the fact that the functional forms of relevant distance, revenue, cost, and/or profit functions are generally unknown. SFMs merely assume that these functions exist.

Output-Oriented Models

If the ODF defined by (2.3) exists, then it is linearly homogeneous in outputs. Therefore,

$$D_{O}^{t}\left(x_{it}, q_{it}, z_{it}\right) = q_{1it} D_{O}^{t}\left(x_{it}, q_{it}^{*}, z_{it}\right), \tag{2.25}$$

where $q_{it}^{*} \equiv q_{it} / q_{1it}$ is a vector of normalized outputs. Equivalently,

$$\ln q_{1it} = -\ln D_O^{t}(x_{it}, q_{it}^{*}, z_{it}) - u_{it}, \tag{2.26}$$

where $u_{it} \equiv -\ln OTE^{t}(x_{it}, q_{it}, z_{it}) \geq 0$ is an output-oriented technical inefficiency effect. If the functional form of the ODF is unknown, then (2.26) can be rewritten as

$$\ln q_{1it} = f^{t}(x_{it}, q_{it}^{*}, z_{it}) + v_{it} - u_{it}, \tag{2.27}$$

where $f^{t}(.)$ is an arbitrary approximating function chosen by the researcher, and $v_{it} \equiv -\ln D_O^{t}(x_{it}, q_{it}^{*}, z_{it}) - f^{t}(x_{it}, q_{it}^{*}, z_{it})$ is an unobserved variable that accounts for functional form errors and other sources of statistical noise. The exact nature of the noise component depends on both the SFM and unknown ODF. For example, suppose the SFM is

$$\ln q_{1it} = \alpha + \sum_{h=1}^{H} \gamma_h d_{hit} + \sum_{j=1}^{J} \delta_j \ln z_{jit} + \sum_{m=1}^{M} \beta_m \ln x_{mit} - \sum_{n=1}^{N} \xi_n \ln q_{nit}^{*} + v_{it} - u_{it}, \tag{2.28}$$

where d_{hit} is a variable that takes the value $t - 10h + 10$ in decade h, 0 in any period prior to decade h, and 10 in any period after decade h; this variable allows the rate of technical progress (TP) to vary by decade. If the ODF is given by (2.4), the noise component in this model is

$$v_{it} = \left[\ln A(t) - \sum_{h=1}^{H} \gamma_h d_{hit} \right] + \left[\sum_{n=1}^{N} \xi_n \ln q_{nit}^{*} - \ln \left(\sum_{n=1}^{N} \gamma_n q_{nit}^{*} \right) \right]. \tag{2.29}$$

The first term on the right-hand side of the above equation can be viewed as a measurement error, and the second term as a functional form error.

Maximum Likelihood (ML) Estimation

The following are two of the most common assumptions found in the stochastic frontier literature:

ML1: u_{it} is an independent $N^{+}(0, \sigma_u^2)$ random variable; and

ML2: v_{it} is an independent $N(0, \sigma_v^2)$ random variable.

Here, *independent* means, *inter alia*, that v_{it} and u_{it} are not correlated with the other explanatory variables or with each other. ML1 says that u_{it} is a half-normal random variable obtained by truncating the $N(0, \sigma_u^2)$ distribution from below, at zero. If both ML1 and ML2 hold true, the ML estimators for the unknown parameters will be consistent.

Bayesian Estimation

There are two problems with the ML estimation approach. First, it is not possible to draw finite sample inferences concerning non-linear functions of the parameters (e.g., inefficiency effects). Second, economic theory often suggests that the parameters of frontier models must satisfy inequality constraints; however, ML methods for imposing these constraints are unsatisfactory (binding inequality constraints will result in estimates that lie precisely on the constraint boundary, incorrectly implying that we know the parameters with certainty). Both these problems can be overcome using a Bayesian estimation approach.

Bayesian estimation involves summarizing everything we know about the unknown parameters in the form of a posterior probability density function (PDF). In the present context, the joint posterior PDF takes the form

$$Pr\left(\beta, \mu, \sigma_u^2, \sigma_v^2 \mid X, y\right) \propto Pr\left(y \mid X, \beta, \mu, \sigma_u^2, \sigma_v^2\right) Pr\left(\beta, \mu, \sigma_u^2, \sigma_v^2\right), \tag{2.30}$$

where y is a vector that contains all observations on the dependent variable, X is a matrix containing all observations on the explanatory variables, $Pr(y \mid X, \beta, \mu, \sigma_u^2, \sigma_v^2)$ is the usual likelihood function (i.e., the function that is maximized in the ML approach), and $Pr(\beta, \mu, \sigma_u^2, \sigma_v^2)$ is the prior PDF (i.e., the PDF that summarizes everything we know about the parameters before the data are observed). In this report, the only prior (or "non-sample") information we have about the parameters is that most of the slope coefficients in our SFM are non-negative.

Bayesian point estimation involves evaluating characteristics (e.g., means and variances) of the marginal posterior PDFs. Finding the marginal posterior PDF for a given parameter involves integrating all other parameters out of the joint posterior PDF. In practice, this is done by drawing random samples (or "simulating") from the joint posterior PDF. Arguably, the most widely used simulation algorithm is the Gibbs sampler. This report implements it using an *R* package written by Plummer (2019).

Decomposing TFP Change

SFA methods can be used to decompose any proper TFPI into a measure of OTEC; a measure of the change in statistical noise; and a combined measure of EC, TC, and OSMEC.[1] Mathematically,

$$\begin{aligned} TFPI\left(x_{ks}, q_{ks}, x_{it}, q_{it}\right) = & \left[\frac{Q\left(q_{it}\right)}{Q\left(q_{ks}\right)} \frac{q_{1ks}}{q_{1it}} \frac{\exp\left[f^t\left(x_{it}, q_{it}^*, z_{it}\right)\right]}{\exp\left[f^s\left(x_{ks}, q_{ks}^*, z_{ks}\right)\right]} \frac{X\left(x_{ks}\right)}{X\left(x_{it}\right)}\right] \\ & \times \left[\frac{\exp\left(-u_{it}\right)}{\exp\left(-u_{ks}\right)}\right]\left[\frac{\exp\left(v_{it}\right)}{\exp\left(v_{ks}\right)}\right]. \end{aligned} \tag{2.31}$$

The first term on the right-hand side of (2.31) represents output-oriented environment, technology, and scale-mix efficiency change (OETSMEC); the second represents OTEC; and the final one represents statistical noise change (SNC). Depending on the form of the SFM, finer output-oriented decompositions of proper TFP indices may be available. For example, if the SFM is given by (2.28), the OETSMEC component in (2.31) can be further decomposed into separate measures of EC, TC, and OSMEC. Mathematically,

$$\begin{aligned} \frac{Q\left(q_{it}\right)}{Q\left(q_{ks}\right)} \frac{q_{1ks}}{q_{1it}} \frac{\exp\left[f^t\left(x_{it}, q_{it}^*, z_{it}\right)\right]}{\exp\left[f^s\left(x_{ks}, q_{ks}^*, z_{ks}\right)\right]} \frac{X\left(x_{ks}\right)}{X\left(x_{it}\right)} = & \left[\frac{\exp\left(\sum_{h=1}^{H} \gamma_h d_{hit}\right)}{\exp\left(\sum_{h=1}^{H} \gamma_h d_{hks}\right)}\right] \\ \times \left[\prod_{j=1}^{J}\left(\frac{z_{jit}}{z_{jks}}\right)^{\delta_m}\right] \times & \left[\frac{Q\left(q_{it}\right)}{Q\left(q_{ks}\right)} \prod_{n=1}^{N}\left(\frac{q_{nks}}{q_{nit}}\right)^{\xi_n} \frac{X\left(x_{ks}\right)}{X\left(x_{it}\right)} \prod_{m=1}^{M}\left(\frac{x_{mit}}{x_{mks}}\right)^{\beta_m}\right]. \end{aligned} \tag{2.32}$$

[1] We estimate the SFM in a way that rules out technical regress. Thus, the only type of TC we permit is TP. For this reason, the rest of this report uses the abbreviation TP instead of TC.

The first term on the right-hand side of (2.32) represents TC, the second term represents EC, and the final term represents OSMEC. If there is only one output, the output components in the OSMEC term vanish. If there is only one input with an associated coefficient of 1, the input components vanish.

In summary, depending on the form of the SFM, SFA methods can be used to decompose any TFPI into the product of EC, TC, OSMEC, OTEC, and SNC (i.e., TFPI = EC × TC × OSMEC × OTEC × SNC).

DATA AND ESTIMATION

This chapter summarizes the data sources, data cleaning procedures, and basic estimation results. The parameter estimates reported in this chapter are used to derive the detailed estimates of TFP and the efficiency changes reported in Chapters 4 and 5.

In O'Donnell and Peyrache (2020, p. 107), we wrote: "Monitoring agricultural productivity change is a matter of measuring output and input change. The main challenge to measuring output and input change (and therefore productivity change) is the collection of accurate data. Not only must data be accurate, they must be collected at a level that is useful for policy-making. The FAO data used in this project is generally too inaccurate and highly-aggregated for good farm-level policy work." In short, we made a recommendation to collect more accurate data for the same exercise. Following this recommendation, we collected new data from the USDA and other sources. The data used in the current report have wider coverage in terms of both countries and variables. As such, they are expected to be more reliable than the data used in our previous report.

Data

In O'Donnell and Peyrache (2020), we used FAO data covering 91 countries over 55 years, from 1961 to 2015. The new dataset comprises USDA, FAO, and WB data on 143 countries over a 61-year period, from 1961 to 2021. The new dataset also includes data on fish output, temperature, and rainfall. This means that, instead of proxying environmental characteristics by using a climate zone classification, we can more accurately account for the effect of climate variability on our estimates of productivity change.

Countries

We included 143 countries in the analysis, divided into five geographical regions (Africa, the Americas, Asia, Europe, and Oceania). Table 2 lists all 143 countries and their macroregional classifications. The countries listed in this table include 18 APO members, namely Bangladesh, Cambodia, Fiji, India, Indonesia, Islamic Republic of Iran (I.R. Iran), Japan, the Republic of Korea (ROK), Lao PDR, Malaysia, Mongolia, Nepal, Pakistan, the Philippines, Sri Lanka, Thailand, Turkiye, and Vietnam. Data for two APO members (Hong Kong and Singapore) were unavailable or considered unreliable.

TABLE 2

LIST OF COUNTRIES ANALYZED IN THIS REPORT

ID	ISO3	Country	Region	OECD	APO
1	AFG	Afghanistan	Asia		
2	AGO	Angola	Africa		

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ID	ISO3	Country	Region	OECD	APO
3	ALB	Albania	Europe		
4	ARE	United Arab Emirates	Asia		
5	ARG	Argentina	Americas		
6	AUS	Australia	Oceania	Yes	
7	AUT	Austria	Europe	Yes	
8	BDI	Burundi	Africa		
9	BEN	Benin	Africa		
10	BFA	Burkina Faso	Africa		
11	BGD	Bangladesh	Asia		Yes
12	BGR	Bulgaria	Europe		
13	BHR	Bahrain	Asia		
14	BHS	Bahamas	Americas		
15	BLZ	Belize	Americas		
16	BOL	Bolivia	Americas		
17	BRA	Brazil	Americas		
18	BRN	Brunei Darussalam	Asia		
19	BTN	Bhutan	Asia		
20	BWA	Botswana	Africa		
21	CAF	Central African Republic	Africa		
22	CAN	Canada	Americas	Yes	
23	CHE	Switzerland	Europe	Yes	
24	CHL	Chile	Americas	Yes	
25	CHN	China	Asia		
26	CIV	Cote d'Ivoire	Africa		
27	CMR	Cameroon	Africa		
28	COD	Congo DR	Africa		
29	COG	Congo Republic	Africa		
30	COL	Colombia	Americas	Yes	
31	COM	Comoros	Africa		
32	CPV	Cabo Verde	Africa		
33	CRI	Costa Rica	Americas	Yes	
34	CUB	Cuba	Americas		
35	CYP	Cyprus	Europe		
36	DEU	Germany	Europe	Yes	
37	DJI	Djibouti	Africa		
38	DNK	Denmark	Europe	Yes	
39	DOM	Dominican Republic	Americas		
40	DZA	Algeria	Africa		
41	ECU	Ecuador	Americas		
42	EGY	Egypt	Africa		
43	ESP	Spain	Europe	Yes	
44	FIN	Finland	Europe	Yes	
45	FJI	Fiji	Oceania		Yes
46	FRA	France	Europe	Yes	
47	GAB	Gabon	Africa		
48	GBR	United Kingdom	Europe	Yes	

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ID	ISO3	Country	Region	OECD	APO
49	GHA	Ghana	Africa		
50	GIN	Guinea	Africa		
51	GMB	Gambia	Africa		
52	GNB	Guinea-Bissau	Africa		
53	GNQ	Equatorial Guinea	Africa		
54	GRC	Greece	Europe	Yes	
55	GTM	Guatemala	Americas		
56	GUY	Guyana	Americas		
57	HND	Honduras	Americas		
58	HTI	Haiti	Americas		
59	HUN	Hungary	Europe	Yes	
60	IDN	Indonesia	Asia		Yes
61	IND	India	Asia		Yes
62	IRL	Ireland	Europe	Yes	
63	IRN	Islamic Republic of Iran	Asia		Yes
64	IRQ	Iraq	Asia		
65	ISL	Iceland	Europe	Yes	
66	ISR	Israel	Asia	Yes	
67	ITA	Italy	Europe	Yes	
68	JAM	Jamaica	Americas		
69	JOR	Jordan	Asia		
70	JPN	Japan	Asia	Yes	Yes
71	KEN	Kenya	Africa		
72	KHM	Cambodia	Asia		Yes
73	KOR	Republic of Korea	Asia	Yes	Yes
74	KWT	Kuwait	Asia		
75	LAO	Lao PDR	Asia		Yes
76	LBN	Lebanon	Asia		
77	LBR	Liberia	Africa		
78	LBY	Libya	Africa		
79	LKA	Sri Lanka	Asia		Yes
80	LSO	Lesotho	Africa		
81	MAR	Morocco	Africa		
82	MDG	Madagascar	Africa		
83	MEX	Mexico	Americas	Yes	
84	MLI	Mali	Africa		
85	MLT	Malta	Europe		
86	MMR	Myanmar	Asia		
87	MNG	Mongolia	Asia		Yes
88	MOZ	Mozambique	Africa		
89	MRT	Mauritania	Africa		
90	MUS	Mauritius	Africa		
91	MWI	Malawi	Africa		
92	MYS	Malaysia	Asia		Yes
93	NAM	Namibia	Africa		
94	NER	Niger	Africa		

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ID	ISO3	Country	Region	OECD	APO
95	NGA	Nigeria	Africa		
96	NIC	Nicaragua	Americas		
97	NLD	Netherlands	Europe	Yes	
98	NOR	Norway	Europe	Yes	
99	NPL	Nepal	Asia		Yes
100	NZL	New Zealand	Oceania	Yes	
101	OMN	Oman	Asia		
102	PAK	Pakistan	Asia		Yes
103	PAN	Panama	Americas		
104	PER	Peru	Americas		
105	PHL	Philippines	Asia		Yes
106	PNG	Papua New Guinea	Oceania		
107	POL	Poland	Europe	Yes	
108	PRI	Puerto Rico (USA)	Americas		
109	PRK	Democratic People's Republic of Korea	Asia		
110	PRT	Portugal	Europe	Yes	
111	PRY	Paraguay	Americas		
112	QAT	Qatar	Asia		
113	ROU	Romania	Europe		
114	RWA	Rwanda	Africa		
115	SAU	Saudi Arabia	Asia		
116	SEN	Senegal	Africa		
117	SLB	Solomon Islands	Oceania		
118	SLE	Sierra Leone	Africa		
119	SLV	El Salvador	Americas		
120	SOM	Somalia	Africa		
121	STP	Sao Tome and Principe	Africa		
122	SUR	Suriname	Americas		
123	SWE	Sweden	Europe	Yes	
124	SWZ	Eswatini	Africa		
125	SYR	Syria	Asia		
126	TCD	Chad	Africa		
127	TGO	Togo	Africa		
128	THA	Thailand	Asia		Yes
129	TLS	Timor-Leste	Asia		
130	TTO	Trinidad and Tobago	Americas		
131	TUN	Tunisia	Africa		
132	TUR	Turkiye	Europe/Asia	Yes	Yes
133	TZA	Tanzania	Africa		
134	UGA	Uganda	Africa		
135	URY	Uruguay	Americas		
136	USA	United States	Americas	Yes	
137	VEN	Venezuela	Americas		
138	VNM	Vietnam	Asia		Yes

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ID	ISO3	Country	Region	OECD	APO
139	VUT	Vanuatu	Oceania		
140	YEM	Yemen	Asia		
141	ZAF	South Africa	Africa		
142	ZMB	Zambia	Africa		
143	ZWE	Zimbabwe	Africa		

ISO, International Organization for Standardization; APO, Asian Productivity Organization.
Source: Authors' data.

Variables

The research team attempted to measure all outputs and inputs involved in agricultural production in each country. Where possible, variables were disaggregated to a level where all items within any output or input category could be considered as reasonably homogeneous (e.g., total agricultural output was disaggregated into crop, livestock, and fish outputs). The research team carefully distinguished between measures of volume (or quantity), price, and value and assembled data on $N = 4$ outputs (crops, animals, fish, and greenhouse gas emissions) and $M = 6$ inputs (land, labor, machinery, livestock, fertilizers, and feed). All variables were normalized to have unit means. Other inputs (e.g., seeds and pesticides) were unobserved and, thus, omitted. This is one source of statistical noise. In this report, we also included two characteristics of production environments: rainfall and temperature. The descriptive statistics for all variables are reported in Table 3.

TABLE 3

DESCRIPTIVE STATISTICS FOR OUTPUTS, INPUTS, AND ENVIRONMENTAL VARIABLES

Variable	Description	Mean	Standard deviation	Minimum	Maximum
q1	Crops	1	3.860	0.0000	70.86
q2	Animals	1	3.474	0.0001	54.49
q3	Fish	1	10.124	0.0000	286.08
q4	Emissions	1	2.762	0.0000	25.25
x1	Land	1	2.961	0.0001	25.80
x2	Labor	1	5.048	0.0001	69.13
x3	Machinery	1	6.356	0.0000	144.08
x4	Livestock	1	2.925	0.0003	27.51
x5	Fertilizer	1	4.087	0.0000	63.48
x6	Feed	1	3.869	0.0000	69.01
z1	Rainfall	1	0.684	0.0091	3.77
z2	Temperature	1	0.197	0.2884	1.26

Source: Authors' data.

Data Cleaning

Cleaning the dataset involved inspecting the minima, maxima, scatterplots, and histograms of the variables; ratios of variables; residuals obtained from simple regression models; and efficiency estimates of simple DEA models. Records were removed or corrected if any input or output variables took negative values, or if essential inputs (e.g., land) took the value 0.

Estimation

The research team used both the DEA and SFA methods to estimate various measures of efficiency. SFA methods were also used to measure TFP change. This section summarizes the main results. The main drawback of DEA is that it does not account for measurement errors and other sources of statistical noise. Hence, the research team used SFA to generate the results in Chapters 4 and 5.

DEA

The DEA estimates of TSME, OSME, and OTE for selected countries and years are reported in Table 4. The interpretation of the estimates is straightforward. For example, the first row indicates that Afghanistan was only 25.5% efficient in 1961, and that this was entirely due to output-oriented scale-mix inefficiency (i.e., TSME = OSME × OTE = 0.255 × 1 = 0.255). The mean values reported at the bottom of Table 2 reveal that this pattern of inefficiency was repeated for most countries in most years.

TABLE 4

DEA RESULTS FOR SELECTED COUNTRIES AND YEARS

ISO3	Country	Year	TSME	OSME	OTE
AFG	Afghanistan	1961	0.255	0.255	1.000
AGO	Angola	1961	0.206	0.213	0.966
ALB	Albania	1961	0.231	0.271	0.851
ARE	United Arab Emirates	1961	0.394	0.394	1.000
ARG	Argentina	1961	0.268	0.268	1.000
AUS	Australia	1961	0.189	0.189	1.000
VNM	Vietnam	1961	0.212	0.212	1.000
VUT	Vanuatu	1961	0.229	0.229	1.000
YEM	Yemen	1961	0.094	0.094	1.000
ZAF	South Africa	1961	0.192	0.258	0.744
ZMB	Zambia	1961	0.108	0.223	0.483
ZWE	Zimbabwe	1961	0.114	0.180	0.632
AFG	Afghanistan	2021	0.131	0.131	1.000
AGO	Angola	2021	0.017	0.017	1.000
ALB	Albania	2021	0.053	0.053	1.000
ARE	United Arab Emirates	2021	0.034	0.034	1.000
ARG	Argentina	2021	0.027	0.027	1.000
AUS	Australia	2021	0.029	0.029	1.000
VNM	Vietnam	2021	0.179	0.179	1.000
VUT	Vanuatu	2021	0.017	0.019	0.861
YEM	Yemen	2021	0.017	0.017	1.000
ZAF	South Africa	2021	0.032	0.032	1.000
ZMB	Zambia	2021	0.026	0.026	1.000
ZWE	Zimbabwe	2021	0.028	0.028	1.000
Min.			0.004	0.004	0.401
Mean			0.239	0.246	0.960
Max.			1.000	1.000	1.000

DEA, data envelopment analysis; ISO, International Organization for Standardization; OSME, output-oriented scale-mix efficiency; OTE, output-oriented technical efficiency; TSME, technical and scale-mix efficiency.
Source: Authors' data.

SFA

The ML estimates of the unknown parameters in (2.28) are reported in Table 5. Bayesian estimation provides estimates that are consistent with prior expectations regarding the signs of various coefficients. The coefficients of the decadal variables indicate that world agriculture has experienced TP at an average annual rate, ranging from 0.02% (in the 1970s) to 1.8% (in the 2020s). The coefficients of the log inputs sum to 1.004, indicating that the production frontier exhibits near-CRS. The coefficients of the log-normalized outputs indicate that the shadow revenue shares of crops, animals, fish, and greenhouse gas emissions are 0.219, 0.245, 0.000, and 0.535, respectively.

TABLE 5

BAYESIAN PARAMETER ESTIMATES

Variable	Estimate	Lower bound	Upper bound
Constant	3.891e-02	–6.544e-02	1.125e-01
1960s	3.052e-04	1.052e-05	1.108e-03
1970s	2.113e-04	6.383e-06	7.351e-04
1980s	4.146e-03	2.061e-03	6.392e-03
1990s	6.245e-03	3.945e-03	8.423e-03
2000s	6.135e-04	1.497e-05	2.029e-03
2010s	6.947e-04	2.424e-05	2.166e-03
2020s	1.878e-02	5.876e-04	5.325e-02
Rain	0.228	0.197	0.261
Rain^2	–0.044	–0.056	–0.032
Temperature	0.155	0.007	0.384
Temperature^2	–0.181	–0.306	–0.094
Land	0.133	0.123	0.143
Labor	0.059	0.052	0.066
Machinery	0.039	0.034	0.043
Livestock	0.580	0.568	0.592
Fertilizer	0.114	0.106	0.122
Feed	0.080	0.075	0.086
Crops	0.219	0.209	0.229
Animals	0.245	0.233	0.257
Fish	0.000	0.000	0.001
Emissions	0.535	0.525	0.546

Source: Authors' data.

The OTE estimates for the selected countries in the selected years are reported in Table 6.

TABLE 6

SFA EFFICIENCY ESTIMATES

ISO3	Country	Year	OTE
AFG	Afghanistan	1961	0.893
AGO	Angola	1961	0.908
ALB	Albania	1961	0.900

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ISO3	Country	Year	OTE
ARE	United Arab Emirates	1961	0.952
ARG	Argentina	1961	0.926
AUS	Australia	1961	0.924
VNM	Vietnam	1961	0.935
VUT	Vanuatu	1961	0.934
YEM	Yemen	1961	0.902
ZAF	South Africa	1961	0.871
ZMB	Zambia	1961	0.841
ZWE	Zimbabwe	1961	0.861
AFG	Afghanistan	2021	0.914
AGO	Angola	2021	0.929
ALB	Albania	2021	0.919
ARE	United Arab Emirates	2021	0.927
ARG	Argentina	2021	0.921
AUS	Australia	2021	0.936
VNM	Vietnam	2021	0.912
VUT	Vanuatu	2021	0.895
YEM	Yemen	2021	0.908
ZAF	South Africa	2021	0.908
ZMB	Zambia	2021	0.930
ZWE	Zimbabwe	2021	0.911
Minimum			0.204
Mean			0.898
Maximum			0.967

ISO, International Organization for Standardization; OTE, output-oriented technical efficiency; SFA, stochastic frontier analysis.
Source: Authors' data.

TFP

The TFPI used in this report is an additive index. Additive TFPI values can be computed using any non-negative measures of relative value as weights. The output aggregator function used to compute the TFPI in this project is

$$Q(q_{it}) = 1.0q_{1it} + 1.2q_{2it} + 17.2q_{3it}. \quad (3.1)$$

Greenhouse gas emissions are regarded as an unproductive activity; hence, this output has been given a weight of zero. On the input side, the input aggregator function is

$$X(x_{it}) = 0.133x_{1it} + 0.059x_{2it} + 0.039x_{3it} + 0.580x_{4it} + 0.114x_{5it} + 0.080x_{6it}. \quad (3.2)$$

DEA and SFA were both used to decompose the TFPI into various measures of EC, TC, and efficiency change. The DEA results were generally similar to the SFA results but were affected by measurement error in our dataset; therefore, we decided to use the SFA results for the rest of the report. In general, SFA results are preferable to DEA results in the presence of measurement errors and other sources of statistical noise.

PRODUCTIVITY CHANGE BY REGION

This chapter reports our estimates of average productivity and efficiency changes for Africa, the Americas, Asia, and Europe. It focuses on measures of land, labor, capital, and TFP change. The additive TFPI discussed in the previous chapter was used as the measure of TFP change. The averages reported in this chapter are calculated as unweighted geometric averages of country-specific results.

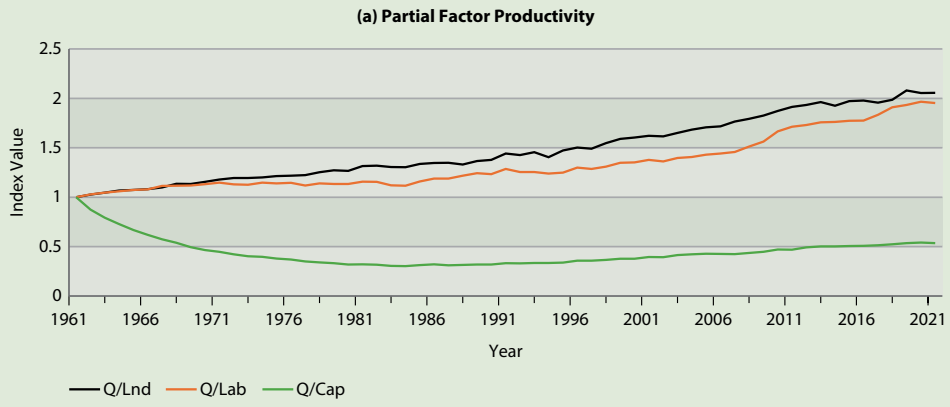
Africa

Figure 3 reports the average changes in productivity in Africa from 1961 to 2021. The index numbers used to construct this figure are shown in Table 7. Figure 3(a) indicates that the average land productivity increased steadily and at a much faster rate than the average labor productivity over the sample period; in 2021, the average land (labor) productivity was 2.056 (1.952) times higher than that in 1961. The figure also indicates that the average capital productivity fell in the first half of the sample period before recovering slightly in the second half; in 1984 (2021), the average capital productivity was 0.302 (0.536) of that in 1961. Figure 3(b) indicates that the average TFP was 1.442 times higher in 2021 than in 1961. This increase can be explained as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 1.151 \times 0.987 \times 1.370 \times 0.980 \times 0.945 \\ &= 1.442. \end{aligned}$$

FIGURE 3

AVERAGE PRODUCTIVITY CHANGE IN AFRICA (CF. AFRICA IN 1961)



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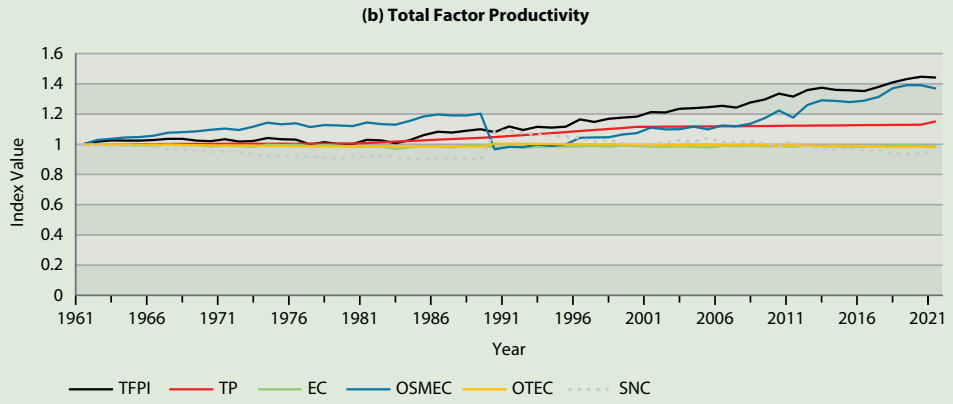

Source: Authors' illustration.

This decomposition indicates that, on average, (i) changes in the production environment (EC) had a small impact on measured TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a 37% increase in TFP, (iv) changes in technical efficiency (OTEC) had a negligible impact on TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) also had a negligible impact on TFP.

TABLE 7

AVERAGE PRODUCTIVITY CHANGE IN AFRICA (CF. AFRICA IN 1961)

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.027	1.028	0.874	1.017	1.000	1.000	1.028	0.998	0.992
3	1963	1.046	1.046	0.792	1.025	1.001	1.002	1.036	0.998	0.989
4	1964	1.067	1.059	0.729	1.025	1.001	0.993	1.045	0.999	0.988
5	1965	1.074	1.073	0.668	1.024	1.001	0.991	1.047	0.997	0.988
6	1966	1.081	1.079	0.619	1.029	1.002	0.992	1.057	0.999	0.981
7	1967	1.098	1.114	0.574	1.037	1.002	1.000	1.076	0.996	0.966
8	1968	1.135	1.116	0.538	1.035	1.002	0.995	1.080	0.995	0.966
9	1969	1.135	1.118	0.493	1.024	1.002	0.995	1.086	0.994	0.952
10	1970	1.156	1.132	0.464	1.021	1.003	0.985	1.096	0.992	0.950
11	1971	1.179	1.146	0.447	1.033	1.003	0.990	1.103	0.992	0.951
12	1972	1.194	1.130	0.421	1.018	1.003	0.988	1.095	0.991	0.947
13	1973	1.194	1.126	0.402	1.021	1.003	0.984	1.117	0.992	0.934
14	1974	1.200	1.147	0.396	1.042	1.004	0.997	1.143	0.988	0.922
15	1975	1.213	1.140	0.379	1.033	1.004	0.994	1.132	0.989	0.924
16	1976	1.218	1.146	0.370	1.031	1.004	0.997	1.139	0.987	0.917
17	1977	1.223	1.118	0.350	0.999	1.004	0.988	1.114	0.987	0.916
18	1978	1.252	1.140	0.341	1.013	1.004	0.996	1.127	0.985	0.913

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
19	1979	1.272	1.133	0.332	1.002	1.005	0.991	1.125	0.985	0.909
20	1980	1.266	1.134	0.319	1.002	1.005	0.985	1.121	0.986	0.917
21	1981	1.315	1.157	0.320	1.030	1.009	0.986	1.144	0.987	0.916
22	1982	1.319	1.156	0.317	1.026	1.013	0.986	1.134	0.987	0.918
23	1983	1.305	1.121	0.306	1.008	1.017	0.969	1.130	0.986	0.918
24	1984	1.303	1.117	0.302	1.026	1.022	0.980	1.155	0.984	0.902
25	1985	1.336	1.160	0.312	1.061	1.026	0.987	1.185	0.983	0.899
26	1986	1.347	1.189	0.321	1.083	1.030	0.985	1.198	0.984	0.906
27	1987	1.349	1.188	0.312	1.078	1.034	0.979	1.190	0.986	0.907
28	1988	1.331	1.217	0.315	1.089	1.039	0.992	1.191	0.984	0.902
29	1989	1.365	1.242	0.319	1.100	1.043	0.994	1.202	0.984	0.898
30	1990	1.377	1.233	0.318	1.080	1.047	0.978	0.966	1.005	1.086
31	1991	1.442	1.286	0.332	1.117	1.054	0.986	0.983	1.004	1.090
32	1992	1.426	1.255	0.330	1.094	1.061	0.976	0.981	1.004	1.074
33	1993	1.455	1.254	0.334	1.116	1.067	0.982	0.998	1.002	1.065
34	1994	1.406	1.238	0.334	1.110	1.074	0.986	0.989	1.002	1.058
35	1995	1.473	1.249	0.338	1.116	1.081	0.984	1.000	0.999	1.051
36	1996	1.502	1.299	0.358	1.165	1.087	0.986	1.042	1.003	1.039
37	1997	1.490	1.287	0.358	1.148	1.094	0.989	1.045	0.999	1.016
38	1998	1.548	1.309	0.366	1.168	1.101	0.984	1.046	1.001	1.029
39	1999	1.589	1.347	0.378	1.177	1.108	0.991	1.065	0.998	1.008
40	2000	1.603	1.352	0.378	1.183	1.115	0.988	1.073	0.996	1.004
41	2001	1.621	1.378	0.394	1.213	1.116	0.985	1.110	0.995	0.999
42	2002	1.615	1.361	0.393	1.210	1.116	0.981	1.099	0.993	1.013
43	2003	1.650	1.396	0.414	1.235	1.117	0.986	1.099	0.994	1.026
44	2004	1.683	1.406	0.421	1.239	1.118	0.983	1.116	0.993	1.017
45	2005	1.707	1.430	0.427	1.245	1.118	0.978	1.098	0.997	1.039
46	2006	1.718	1.442	0.425	1.255	1.119	0.990	1.124	0.993	1.014
47	2007	1.766	1.458	0.424	1.243	1.120	0.986	1.119	0.993	1.013
48	2008	1.792	1.512	0.435	1.277	1.120	0.989	1.136	0.995	1.021
49	2009	1.827	1.562	0.447	1.296	1.121	0.986	1.173	0.995	1.005
50	2010	1.872	1.666	0.471	1.335	1.122	0.988	1.223	0.992	0.993
51	2011	1.914	1.713	0.469	1.316	1.123	0.984	1.177	0.993	1.019
52	2012	1.932	1.731	0.493	1.359	1.123	0.990	1.260	0.990	0.979
53	2013	1.963	1.757	0.502	1.374	1.124	0.986	1.291	0.989	0.971
54	2014	1.926	1.762	0.501	1.360	1.125	0.986	1.287	0.989	0.964
55	2015	1.972	1.774	0.506	1.357	1.126	0.981	1.279	0.989	0.971
56	2016	1.979	1.776	0.509	1.352	1.126	0.984	1.289	0.988	0.959
57	2017	1.956	1.834	0.514	1.380	1.127	0.989	1.313	0.985	0.957
58	2018	1.986	1.909	0.524	1.409	1.128	0.990	1.370	0.981	0.938
59	2019	2.080	1.933	0.535	1.432	1.129	0.995	1.390	0.982	0.934
60	2020	2.054	1.966	0.542	1.447	1.130	0.989	1.391	0.984	0.946
61	2021	2.056	1.952	0.536	1.442	1.151	0.987	1.370	0.980	0.945

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

The Americas

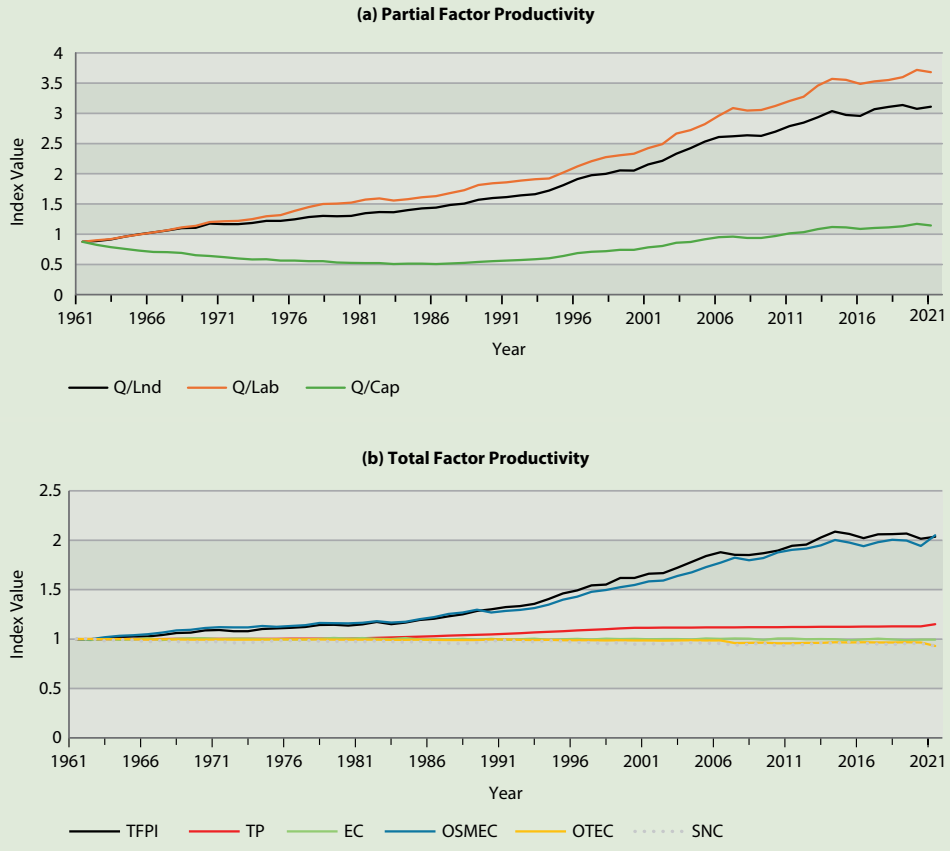
Figure 4 reports the average changes in productivity in the Americas from 1961 to 2021. The index numbers used to construct this figure are shown in Table 8. Figure 4(a) indicates that the average land and labor productivity increased steadily and at almost exactly the same rate over the sample period: In 2021, the average land (labor) productivity was 3.196 (3.756) times higher than that in 1961. This figure also indicates that the average capital productivity fell in the first half of the sample period before fully recovering in the second half; in 1987 (2021), the average capital productivity was 0.646 (1.265) of that in 1961. Figure 4(b) indicates that the average TFP was 2.036 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.996 \times 1.151 \times 2.050 \times 0.931 \times 0.931 \\ &= 2.036. \end{aligned}$$

This decomposition indicates that, on average, (i) changes in the production environment (EC) had no impact on measured TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix

FIGURE 4

AVERAGE PRODUCTIVITY CHANGE IN THE AMERICAS (CF. THE AMERICAS IN 1961)



Source: Authors' illustration.

efficiency (OSMEC) led to a 105.0% increase in TFP, (iv) changes in technical efficiency (OTEC) contributed to a 6.9% reduction in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) had a negative but small impact on TFP.

TABLE 8

AVERAGE PRODUCTIVITY CHANGE IN THE AMERICAS (CF. THE AMERICAS IN 1961)

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.012	1.023	0.951	0.996	1.000	0.991	0.999	1.001	1.005
3	1963	1.038	1.044	0.913	1.004	1.001	1.004	1.019	0.998	0.983
4	1964	1.085	1.083	0.884	1.021	1.001	0.992	1.034	1.000	0.994
5	1965	1.120	1.118	0.855	1.028	1.001	0.997	1.040	0.999	0.991
6	1966	1.151	1.152	0.833	1.027	1.002	1.009	1.050	0.995	0.973
7	1967	1.183	1.187	0.831	1.042	1.002	0.990	1.065	0.999	0.987
8	1968	1.221	1.235	0.820	1.062	1.002	1.003	1.088	0.996	0.975
9	1969	1.228	1.258	0.781	1.065	1.002	1.009	1.094	0.994	0.968
10	1970	1.296	1.320	0.770	1.088	1.003	1.008	1.113	0.995	0.973
11	1971	1.287	1.332	0.751	1.093	1.003	1.001	1.121	0.996	0.975
12	1972	1.287	1.341	0.729	1.080	1.003	1.004	1.119	0.995	0.963
13	1973	1.305	1.368	0.714	1.081	1.003	1.004	1.119	0.994	0.964
14	1974	1.339	1.413	0.717	1.103	1.004	1.000	1.134	0.995	0.973
15	1975	1.339	1.434	0.694	1.108	1.004	1.000	1.125	0.998	0.984
16	1976	1.364	1.502	0.695	1.114	1.004	0.996	1.133	0.998	0.985
17	1977	1.401	1.563	0.685	1.123	1.004	0.997	1.142	0.997	0.986
18	1978	1.421	1.613	0.684	1.144	1.004	1.003	1.163	0.997	0.979
19	1979	1.413	1.621	0.663	1.146	1.005	1.012	1.161	0.995	0.976
20	1980	1.421	1.637	0.657	1.137	1.005	1.005	1.159	0.995	0.976
21	1981	1.465	1.687	0.653	1.150	1.009	1.011	1.166	0.994	0.972
22	1982	1.484	1.703	0.654	1.174	1.013	1.003	1.181	0.995	0.983
23	1983	1.481	1.669	0.638	1.151	1.017	1.001	1.168	0.994	0.974
24	1984	1.513	1.693	0.642	1.167	1.022	1.011	1.176	0.993	0.967
25	1985	1.543	1.722	0.644	1.194	1.026	0.997	1.203	0.995	0.976
26	1986	1.556	1.743	0.638	1.205	1.030	0.997	1.222	0.993	0.967
27	1987	1.598	1.791	0.646	1.230	1.034	0.997	1.256	0.991	0.958
28	1988	1.622	1.839	0.655	1.251	1.039	1.003	1.269	0.991	0.954
29	1989	1.683	1.922	0.673	1.286	1.043	0.995	1.297	0.991	0.965
30	1990	1.711	1.951	0.684	1.302	1.047	1.002	1.270	0.996	0.981
31	1991	1.725	1.967	0.693	1.323	1.054	0.993	1.285	0.996	0.988
32	1992	1.756	1.994	0.704	1.334	1.061	0.998	1.295	0.993	0.979
33	1993	1.774	2.018	0.714	1.357	1.067	1.005	1.314	0.990	0.973
34	1994	1.832	2.029	0.732	1.406	1.074	0.992	1.348	0.993	0.985
35	1995	1.920	2.126	0.770	1.462	1.081	1.000	1.399	0.990	0.978
36	1996	2.018	2.227	0.815	1.492	1.087	1.004	1.429	0.990	0.967
37	1997	2.082	2.309	0.839	1.543	1.094	0.997	1.478	0.990	0.967
38	1998	2.105	2.374	0.846	1.553	1.101	1.005	1.496	0.986	0.951

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
39	1999	2.159	2.408	0.870	1.619	1.108	1.001	1.526	0.990	0.966
40	2000	2.156	2.431	0.868	1.619	1.115	1.003	1.547	0.987	0.948
41	2001	2.258	2.521	0.910	1.661	1.116	0.999	1.583	0.988	0.953
42	2002	2.317	2.587	0.932	1.668	1.116	1.001	1.593	0.985	0.951
43	2003	2.432	2.759	0.983	1.722	1.117	1.001	1.639	0.987	0.952
44	2004	2.522	2.815	0.997	1.781	1.118	0.998	1.677	0.988	0.964
45	2005	2.629	2.912	1.039	1.840	1.118	1.007	1.728	0.987	0.958
46	2006	2.704	3.050	1.075	1.879	1.119	1.003	1.773	0.988	0.956
47	2007	2.714	3.175	1.085	1.853	1.120	1.007	1.823	0.961	0.939
48	2008	2.732	3.135	1.062	1.850	1.120	1.006	1.797	0.963	0.948
49	2009	2.723	3.144	1.063	1.870	1.121	0.992	1.819	0.965	0.958
50	2010	2.790	3.208	1.093	1.896	1.122	1.008	1.877	0.958	0.933
51	2011	2.880	3.290	1.137	1.943	1.123	1.008	1.903	0.958	0.942
52	2012	2.939	3.357	1.154	1.957	1.123	0.999	1.915	0.963	0.946
53	2013	3.023	3.538	1.207	2.028	1.124	1.001	1.948	0.962	0.962
54	2014	3.125	3.649	1.239	2.087	1.125	0.998	2.004	0.968	0.959
55	2015	3.063	3.633	1.232	2.063	1.126	0.988	1.976	0.967	0.971
56	2016	3.046	3.568	1.209	2.020	1.126	0.997	1.940	0.969	0.957
57	2017	3.155	3.609	1.223	2.059	1.127	1.005	1.981	0.965	0.951
58	2018	3.194	3.629	1.235	2.062	1.128	0.997	2.005	0.966	0.947
59	2019	3.224	3.677	1.252	2.069	1.129	0.989	1.998	0.969	0.957
60	2020	3.163	3.795	1.291	2.016	1.130	0.995	1.941	0.966	0.956
61	2021	3.196	3.756	1.265	2.036	1.151	0.996	2.050	0.931	0.931

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Asia

Figure 5 reports the average changes in measured productivity in Asia from 1961 to 2021. The index numbers used to construct this figure are shown in Table 9. Figure 5(a) indicates that the average land productivity increased steadily and somewhat faster than the average labor productivity over the sample period; in 2021, the measure of average land (labor) productivity was 5.015 (6.482) times higher than that in 1961. This figure also indicates that the average capital productivity fell in the first half of the sample period and remained relatively low; in 2021, the measure of average capital productivity was 23.4% of that in 1961. Figure 5(b) indicates that the average TFP was more than twice as high in 2021 than in 1961. The breakdown of this increase is as follows:

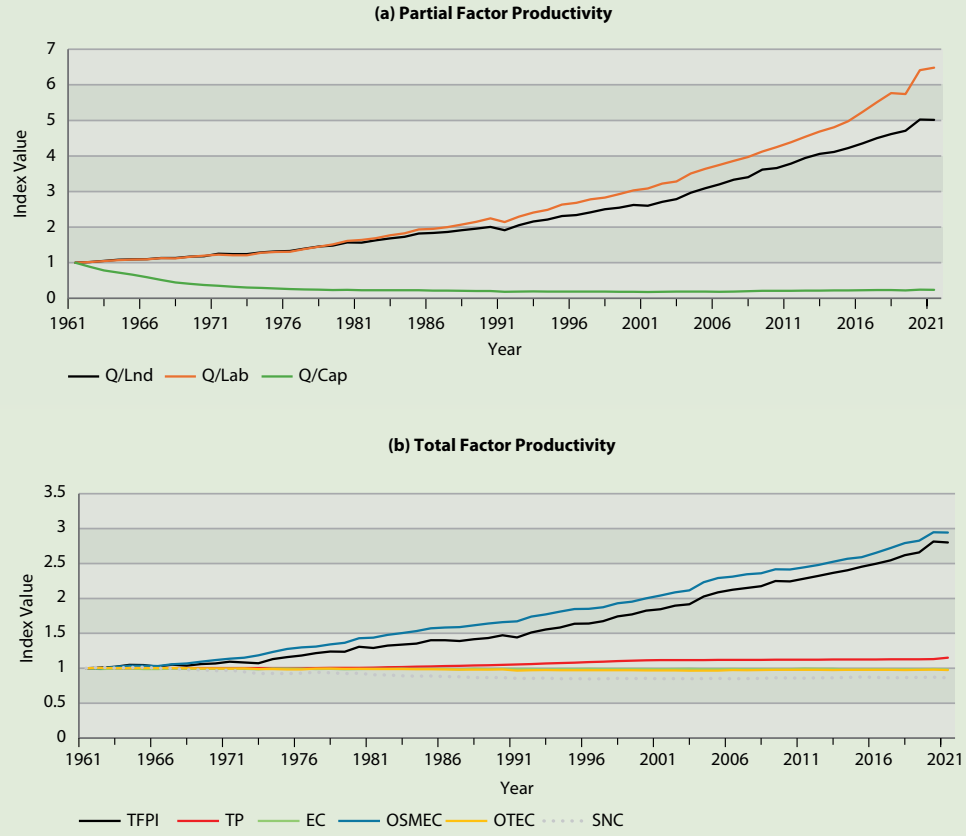
$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.983 \times 1.151 \times 2.943 \times 0.975 \times 0.863 \\ &= 2.901. \end{aligned}$$

This decomposition indicates that, on average, (i) changes in the production environment (EC) had almost no impact on measured TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a 194.3% increase in TFP, (iv) changes in technical efficiency

(OTEC) had a small impact on TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) led to a 13.7% fall in measured TFP.

FIGURE 5

AVERAGE PRODUCTIVITY CHANGE IN ASIA (CF. ASIA IN 1961)



Source: Authors' illustration.

TABLE 9

AVERAGE PRODUCTIVITY CHANGE IN ASIA (CF. ASIA IN 1961)

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.019	1.016	0.885	1.008	1.000	0.989	0.999	1.004	1.016
3	1963	1.049	1.046	0.786	1.021	1.001	0.996	1.019	1.002	1.004
4	1964	1.082	1.071	0.721	1.049	1.001	0.997	1.036	1.004	1.012
5	1965	1.093	1.086	0.661	1.046	1.001	0.989	1.037	1.003	1.014
6	1966	1.098	1.092	0.590	1.024	1.002	0.989	1.031	1.002	1.001
7	1967	1.131	1.129	0.516	1.051	1.002	0.993	1.058	1.002	0.997

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
8	1968	1.132	1.122	0.446	1.037	1.002	0.992	1.069	0.999	0.977
9	1969	1.170	1.162	0.404	1.061	1.002	0.992	1.095	0.997	0.977
10	1970	1.181	1.197	0.371	1.068	1.003	0.993	1.117	0.998	0.963
11	1971	1.250	1.224	0.353	1.095	1.003	0.994	1.137	0.996	0.970
12	1972	1.242	1.210	0.327	1.084	1.003	0.992	1.152	0.996	0.949
13	1973	1.242	1.210	0.303	1.072	1.003	0.986	1.186	0.989	0.923
14	1974	1.288	1.279	0.290	1.132	1.004	0.997	1.233	0.989	0.927
15	1975	1.317	1.302	0.275	1.158	1.004	0.997	1.275	0.984	0.922
16	1976	1.331	1.307	0.258	1.183	1.004	0.994	1.298	0.984	0.928
17	1977	1.392	1.384	0.248	1.217	1.004	0.988	1.310	0.994	0.942
18	1978	1.454	1.448	0.240	1.239	1.004	0.990	1.341	0.993	0.935
19	1979	1.480	1.516	0.232	1.237	1.005	0.986	1.364	0.992	0.922
20	1980	1.570	1.613	0.234	1.306	1.005	0.989	1.430	0.991	0.928
21	1981	1.564	1.639	0.224	1.291	1.009	0.991	1.439	0.989	0.907
22	1982	1.626	1.691	0.225	1.323	1.013	0.990	1.478	0.988	0.903
23	1983	1.683	1.771	0.228	1.339	1.017	0.993	1.504	0.988	0.892
24	1984	1.725	1.824	0.225	1.353	1.022	0.992	1.531	0.985	0.886
25	1985	1.820	1.935	0.223	1.402	1.026	0.990	1.573	0.987	0.889
26	1986	1.836	1.954	0.216	1.402	1.030	0.992	1.583	0.984	0.880
27	1987	1.866	2.000	0.213	1.391	1.034	0.984	1.588	0.981	0.878
28	1988	1.911	2.071	0.210	1.415	1.039	0.993	1.614	0.980	0.867
29	1989	1.958	2.147	0.204	1.433	1.043	0.988	1.639	0.981	0.865
30	1990	2.007	2.243	0.202	1.472	1.047	0.992	1.661	0.983	0.868
31	1991	1.915	2.143	0.185	1.440	1.054	0.989	1.671	0.965	0.856
32	1992	2.056	2.295	0.189	1.511	1.061	0.989	1.739	0.971	0.854
33	1993	2.158	2.412	0.191	1.555	1.067	0.983	1.770	0.974	0.860
34	1994	2.213	2.486	0.189	1.584	1.074	0.987	1.810	0.973	0.848
35	1995	2.310	2.632	0.187	1.638	1.081	0.988	1.848	0.973	0.853
36	1996	2.338	2.684	0.185	1.641	1.087	0.992	1.850	0.971	0.847
37	1997	2.413	2.780	0.186	1.675	1.094	0.989	1.875	0.972	0.849
38	1998	2.502	2.831	0.186	1.742	1.101	0.988	1.929	0.971	0.854
39	1999	2.549	2.930	0.184	1.772	1.108	0.989	1.952	0.971	0.853
40	2000	2.621	3.030	0.184	1.825	1.115	0.989	2.002	0.968	0.854
41	2001	2.599	3.086	0.176	1.844	1.116	0.985	2.041	0.968	0.849
42	2002	2.711	3.223	0.181	1.897	1.116	0.988	2.086	0.967	0.852
43	2003	2.789	3.286	0.185	1.916	1.117	0.991	2.115	0.965	0.848
44	2004	2.968	3.508	0.186	2.028	1.118	0.987	2.233	0.967	0.851
45	2005	3.093	3.640	0.187	2.086	1.118	0.985	2.293	0.966	0.854
46	2006	3.203	3.749	0.182	2.123	1.119	0.989	2.312	0.976	0.850
47	2007	3.331	3.863	0.186	2.150	1.120	0.987	2.346	0.972	0.853
48	2008	3.405	3.973	0.198	2.175	1.120	0.987	2.360	0.973	0.856
49	2009	3.616	4.126	0.211	2.249	1.121	0.984	2.416	0.977	0.864
50	2010	3.661	4.251	0.209	2.244	1.122	0.985	2.414	0.977	0.861
51	2011	3.788	4.384	0.212	2.284	1.123	0.993	2.446	0.978	0.857
52	2012	3.945	4.537	0.214	2.324	1.123	0.991	2.479	0.976	0.863

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
53	2013	4.057	4.688	0.217	2.366	1.124	0.991	2.526	0.975	0.862
54	2014	4.113	4.805	0.220	2.403	1.125	0.980	2.567	0.978	0.868
55	2015	4.222	4.976	0.222	2.455	1.126	0.984	2.592	0.978	0.874
56	2016	4.355	5.240	0.225	2.497	1.126	0.985	2.652	0.977	0.869
57	2017	4.499	5.513	0.232	2.545	1.127	0.983	2.722	0.977	0.863
58	2018	4.616	5.768	0.230	2.618	1.128	0.985	2.792	0.975	0.866
59	2019	4.711	5.743	0.222	2.659	1.129	0.983	2.828	0.977	0.868
60	2020	5.024	6.415	0.244	2.815	1.130	0.989	2.947	0.979	0.873
61	2021	5.015	6.482	0.234	2.801	1.151	0.983	2.943	0.975	0.863

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

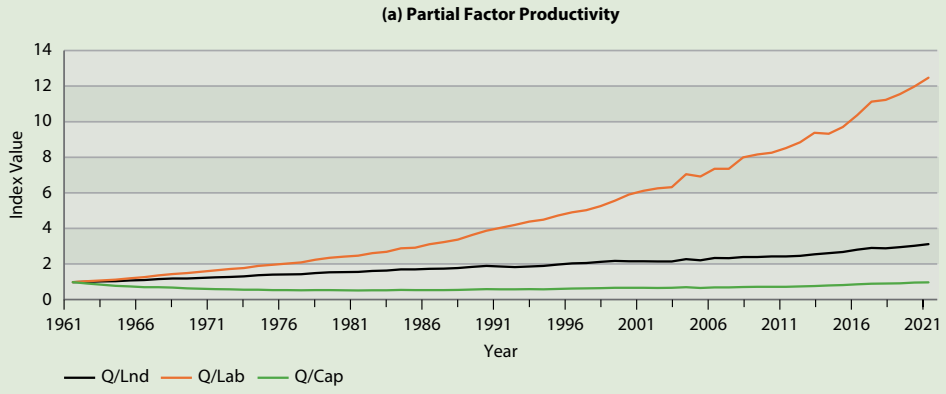
Europe

Figure 6 reports the average changes in productivity in Europe from 1961 to 2021. The index numbers used to construct this figure are shown in Table 10. Figure 6(a) indicates that the average land productivity increased steadily but at a much lower rate than the average labor productivity over the sample period; in 2021, the average land (labor) productivity was 3.145 (12.537) times higher than that in 1961. This figure also indicates that the average capital productivity fell slightly in the first half of the sample period and remained relatively low. Figure 6(b) indicates that the average TFP was 2.640 times higher in 2021 than in 1961. The following is the decomposition of this increase:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 1.003 \times 1.151 \times 1.879 \times 1.022 \times 1.191 \\ &= 2.640. \end{aligned}$$

FIGURE 6

AVERAGE PRODUCTIVITY CHANGE IN EUROPE (CF. EUROPE IN 1961)



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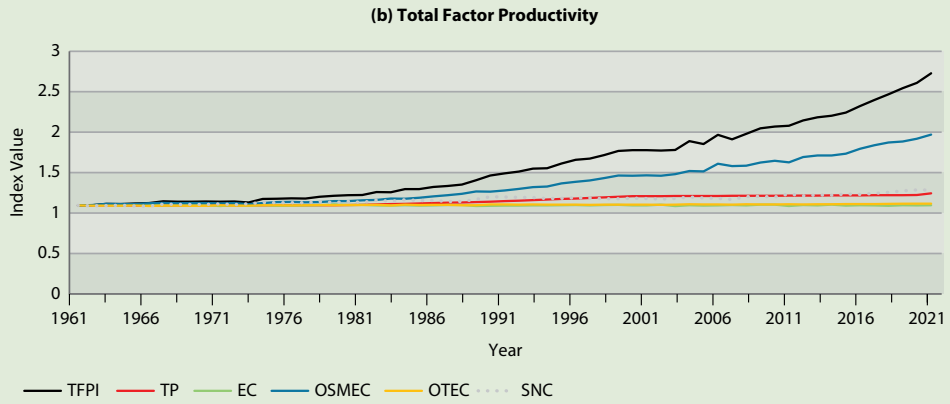

Source: Authors' illustration.

The decomposition indicates that, on average, (i) changes in the production environment (EC) had no impact on measured TFP, (ii) TP led to a 15.1% increase in TFP, (iii) scale-mix efficiency (OSMEC) led to a 87.9% increase in TFP, (iv) changes in technical efficiency (OTEC) led to a 2.2% increase in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) led to a 19.1% increase in TFP.

TABLE 10

AVERAGE PRODUCTIVITY CHANGE IN EUROPE (CF. EUROPE IN 1961)

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.020	1.050	0.918	1.003	1.000	1.003	1.005	0.998	0.996
3	1963	1.046	1.102	0.853	1.022	1.001	1.005	1.019	0.998	0.999
4	1964	1.058	1.136	0.790	1.018	1.001	0.998	1.018	0.998	1.003
5	1965	1.094	1.214	0.756	1.025	1.001	1.010	1.019	1.002	0.993
6	1966	1.123	1.277	0.719	1.031	1.002	1.016	1.028	0.994	0.991
7	1967	1.178	1.382	0.719	1.053	1.002	1.000	1.032	1.000	1.018
8	1968	1.201	1.462	0.691	1.046	1.002	1.004	1.029	0.998	1.013
9	1969	1.210	1.517	0.650	1.047	1.002	1.004	1.030	0.997	1.013
10	1970	1.233	1.588	0.630	1.050	1.003	1.004	1.031	0.997	1.014
11	1971	1.266	1.659	0.605	1.047	1.003	0.995	1.025	1.003	1.021
12	1972	1.294	1.743	0.589	1.051	1.003	1.004	1.031	0.999	1.012
13	1973	1.326	1.797	0.572	1.038	1.003	0.996	1.016	1.000	1.024
14	1974	1.394	1.910	0.575	1.082	1.004	1.006	1.031	1.003	1.037
15	1975	1.420	1.978	0.554	1.084	1.004	0.997	1.044	1.003	1.034
16	1976	1.438	2.050	0.548	1.089	1.004	1.000	1.045	1.002	1.036
17	1977	1.451	2.109	0.538	1.087	1.004	1.001	1.040	1.003	1.036
18	1978	1.512	2.263	0.549	1.108	1.004	1.004	1.042	1.006	1.048

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
19	1979	1.553	2.369	0.549	1.120	1.005	1.015	1.055	1.003	1.037
20	1980	1.566	2.445	0.540	1.129	1.005	1.006	1.055	1.007	1.052
21	1981	1.572	2.497	0.531	1.130	1.009	1.008	1.064	1.005	1.038
22	1982	1.636	2.641	0.542	1.168	1.013	1.000	1.069	1.010	1.068
23	1983	1.653	2.711	0.538	1.164	1.017	0.999	1.086	1.001	1.053
24	1984	1.718	2.904	0.556	1.203	1.022	1.005	1.083	1.011	1.071
25	1985	1.715	2.945	0.550	1.203	1.026	1.000	1.096	1.007	1.063
26	1986	1.755	3.134	0.555	1.230	1.030	1.001	1.114	1.008	1.063
27	1987	1.760	3.258	0.553	1.242	1.034	1.007	1.128	1.008	1.050
28	1988	1.795	3.402	0.560	1.259	1.039	1.006	1.144	1.003	1.049
29	1989	1.859	3.659	0.578	1.314	1.043	0.993	1.174	1.004	1.077
30	1990	1.913	3.898	0.610	1.372	1.047	0.995	1.172	1.013	1.109
31	1991	1.877	4.067	0.594	1.399	1.054	0.998	1.187	1.013	1.106
32	1992	1.850	4.230	0.591	1.421	1.061	0.998	1.205	1.012	1.101
33	1993	1.882	4.411	0.606	1.457	1.067	1.000	1.227	1.012	1.099
34	1994	1.915	4.521	0.599	1.463	1.074	1.002	1.236	1.011	1.087
35	1995	1.993	4.757	0.611	1.521	1.081	1.004	1.274	1.010	1.090
36	1996	2.054	4.935	0.639	1.567	1.087	1.005	1.293	1.012	1.096
37	1997	2.077	5.062	0.644	1.582	1.094	1.000	1.311	1.009	1.093
38	1998	2.142	5.290	0.662	1.625	1.101	1.007	1.340	1.010	1.084
39	1999	2.199	5.590	0.684	1.677	1.108	1.008	1.371	1.010	1.084
40	2000	2.177	5.948	0.684	1.687	1.115	1.001	1.369	1.011	1.092
41	2001	2.173	6.150	0.685	1.686	1.116	1.001	1.374	1.012	1.087
42	2002	2.166	6.291	0.674	1.681	1.116	1.011	1.369	1.008	1.079
43	2003	2.170	6.359	0.683	1.689	1.117	0.993	1.389	1.010	1.085
44	2004	2.300	7.093	0.716	1.798	1.118	1.003	1.429	1.015	1.106
45	2005	2.232	6.962	0.667	1.762	1.118	1.000	1.423	1.012	1.095
46	2006	2.359	7.400	0.707	1.877	1.119	1.001	1.518	1.013	1.089
47	2007	2.347	7.394	0.702	1.821	1.120	1.005	1.489	1.011	1.075
48	2008	2.414	8.046	0.726	1.889	1.120	1.002	1.493	1.015	1.110
49	2009	2.420	8.203	0.732	1.957	1.121	1.010	1.533	1.014	1.113
50	2010	2.454	8.302	0.737	1.978	1.122	1.012	1.555	1.013	1.107
51	2011	2.450	8.562	0.740	1.988	1.123	0.995	1.534	1.015	1.143
52	2012	2.488	8.895	0.757	2.054	1.123	1.005	1.600	1.014	1.120
53	2013	2.565	9.423	0.785	2.094	1.124	1.002	1.620	1.016	1.129
54	2014	2.637	9.374	0.808	2.113	1.125	1.012	1.620	1.015	1.129
55	2015	2.701	9.751	0.834	2.152	1.126	1.000	1.643	1.018	1.143
56	2016	2.835	10.418	0.875	2.232	1.126	1.005	1.704	1.017	1.138
57	2017	2.926	11.181	0.915	2.309	1.127	1.002	1.747	1.018	1.149
58	2018	2.907	11.284	0.921	2.379	1.128	0.997	1.780	1.019	1.165
59	2019	2.974	11.610	0.933	2.454	1.129	1.003	1.793	1.022	1.182
60	2020	3.051	12.034	0.976	2.521	1.130	1.001	1.828	1.022	1.194
61	2021	3.145	12.537	0.983	2.640	1.151	1.003	1.879	1.022	1.191

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

PRODUCTIVITY CHANGE BY COUNTRY

This chapter reports estimates of productivity and efficiency changes for the following countries: Australia, Bangladesh, Cambodia, China, Fiji, France, Germany, India, Indonesia, I.R. Iran, Japan, the ROK, Lao PDR, Malaysia, Mongolia, Nepal, Pakistan, the Philippines, Sri Lanka, Thailand, the UK, the US, Turkiye, and Vietnam. This includes all APO members, with the exception of Singapore, Hong Kong, and the Republic of China, and some reference OECD members. The three APO members were excluded because of their size and the relatively low importance of their agriculture sector in their respective economies. We also included some non-APO benchmark countries in the report (Australia, China, France, Germany, UK, and USA) to provide readers with some background on how productivity evolved in non-APO economies over the benchmark time period, focusing on measures of land, labor, capital, and TFP change.

Australia

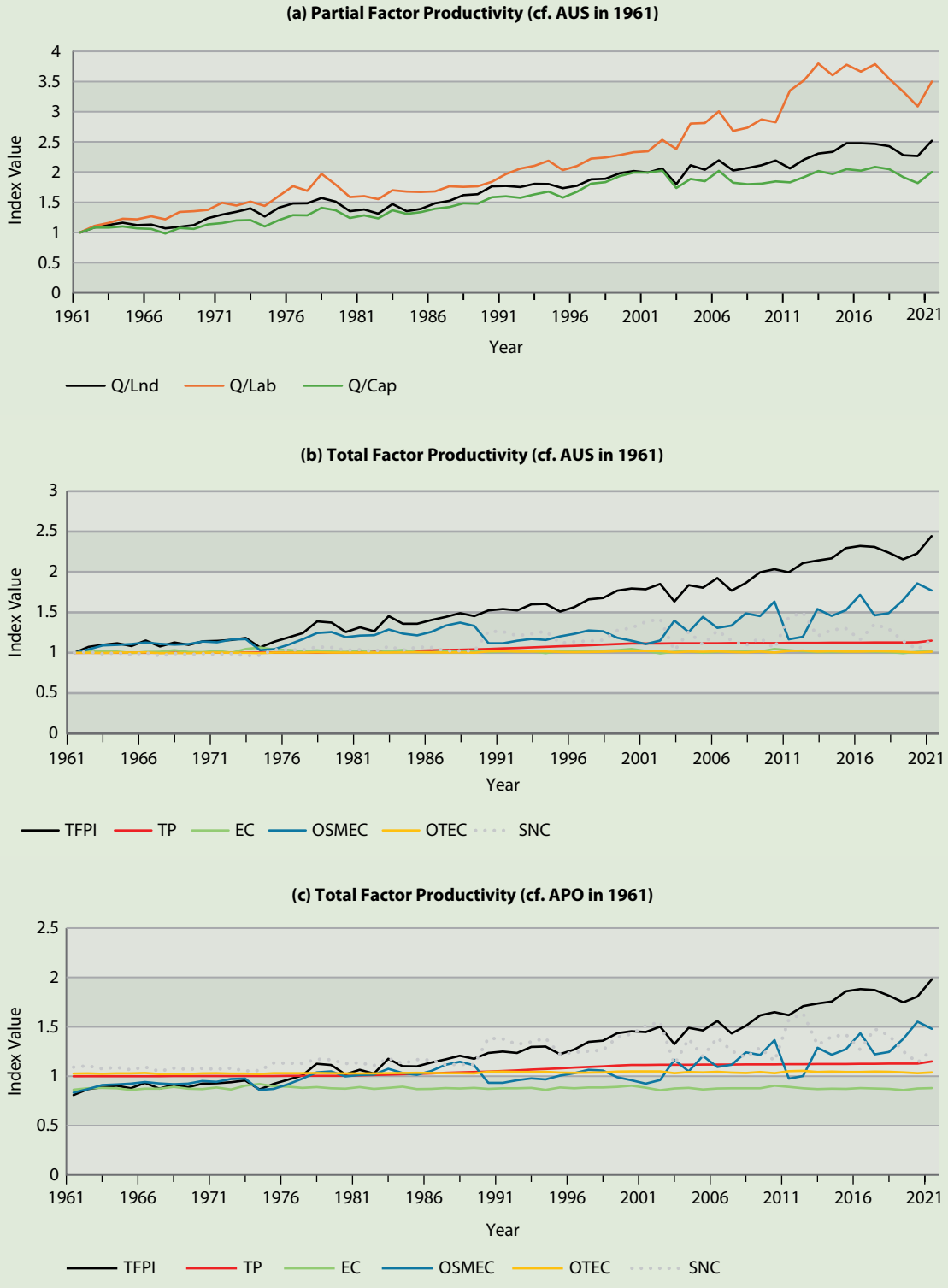
Australia is a major producer of livestock and crop products for both the domestic and export markets. In 2021, its agriculture sector employed 3.1% (1.8%) of the male (female) labor force and contributed 2.7% to the country's GDP (FAO, 2025a, 2025b). The beef industry is the largest agricultural activity by value. Wheat is the most important cereal in terms of area and value. Major problems faced by Australian agriculture include a lack of water security and low soil fertility. Figure 7 reports the estimated changes in agricultural productivity in Australia from 1961 to 2021. The index numbers used to construct this figure are shown in Table 11. Figure 7(a) indicates that land productivity increased at a slower rate than labor productivity but at a faster rate than capital productivity over the sample period; in 2021, the output per unit of land was 2.518 times higher than that in 1961, while the output per unit of labor (capital) was 3.500 (2.000) times higher than that in 1961. Figure 7(b) indicates that the TFP in Australian agriculture was 2.445 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 1.019 \times 1.151 \times 1.771 \times 1.013 \times 1.162 \\ &= 2.445. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a small impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a 77.1% increase in TFP, (iv) improvements in technical efficiency (OTEC) led to a 1.3% increase in TFP, and (v) changes in statistical noise (SNC) accounted for a 16.2% increase in measured TFP.

FIGURE 7

PRODUCTIVITY CHANGE IN AUSTRALIA



Source: Authors' illustration.

TABLE 11

PRODUCTIVITY CHANGE IN AUSTRALIA

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.084	1.110	1.081	1.075	1.000	1.016	1.043	1.002	1.012
3	1963	1.124	1.159	1.081	1.098	1.001	1.021	1.090	0.999	0.986
4	1964	1.162	1.227	1.099	1.118	1.001	1.017	1.098	1.003	0.998
5	1965	1.120	1.219	1.068	1.084	1.001	0.998	1.108	1.003	0.976
6	1966	1.131	1.268	1.060	1.153	1.002	1.012	1.128	1.006	1.002
7	1967	1.069	1.218	0.982	1.080	1.002	1.012	1.111	0.997	0.962
8	1968	1.095	1.340	1.073	1.129	1.002	1.033	1.101	0.999	0.991
9	1969	1.120	1.352	1.058	1.098	1.002	1.012	1.108	0.997	0.980
10	1970	1.238	1.373	1.134	1.142	1.003	1.007	1.141	1.002	0.988
11	1971	1.297	1.492	1.157	1.147	1.003	1.025	1.131	1.004	0.982
12	1972	1.342	1.445	1.199	1.159	1.003	1.002	1.164	1.000	0.990
13	1973	1.398	1.510	1.205	1.183	1.003	1.047	1.168	1.000	0.964
14	1974	1.265	1.441	1.099	1.068	1.004	1.066	1.034	0.997	0.969
15	1975	1.411	1.605	1.206	1.138	1.004	1.040	1.045	1.004	1.039
16	1976	1.480	1.767	1.288	1.191	1.004	1.035	1.101	1.005	1.037
17	1977	1.483	1.688	1.284	1.245	1.004	1.022	1.169	1.004	1.035
18	1978	1.570	1.971	1.409	1.390	1.004	1.030	1.244	1.006	1.073
19	1979	1.511	1.791	1.366	1.374	1.005	1.015	1.257	1.004	1.068
20	1980	1.351	1.586	1.239	1.256	1.005	1.010	1.195	1.003	1.033
21	1981	1.382	1.603	1.282	1.315	1.009	1.030	1.213	1.002	1.041
22	1982	1.311	1.551	1.233	1.266	1.013	1.009	1.218	1.002	1.015
23	1983	1.470	1.699	1.368	1.454	1.017	1.021	1.289	1.004	1.082
24	1984	1.351	1.676	1.309	1.360	1.022	1.035	1.237	1.007	1.033
25	1985	1.388	1.670	1.338	1.358	1.026	1.008	1.216	1.009	1.071
26	1986	1.482	1.680	1.392	1.405	1.030	1.008	1.261	1.006	1.067
27	1987	1.525	1.765	1.421	1.445	1.034	1.018	1.337	1.004	1.022
28	1988	1.617	1.755	1.484	1.490	1.039	1.014	1.373	1.005	1.025
29	1989	1.632	1.764	1.477	1.454	1.043	1.020	1.333	1.002	1.024
30	1990	1.764	1.837	1.582	1.525	1.047	1.009	1.117	1.019	1.268
31	1991	1.770	1.966	1.599	1.543	1.054	1.015	1.119	1.021	1.262
32	1992	1.750	2.058	1.574	1.525	1.061	1.017	1.149	1.016	1.211
33	1993	1.804	2.102	1.631	1.600	1.067	1.021	1.172	1.016	1.234
34	1994	1.801	2.188	1.678	1.605	1.074	0.997	1.160	1.019	1.267
35	1995	1.732	2.031	1.576	1.512	1.081	1.026	1.205	1.010	1.120
36	1996	1.774	2.099	1.675	1.567	1.087	1.016	1.236	1.009	1.137
37	1997	1.879	2.222	1.808	1.662	1.094	1.026	1.275	1.011	1.148
38	1998	1.888	2.241	1.832	1.678	1.101	1.026	1.266	1.013	1.158
39	1999	1.979	2.282	1.933	1.771	1.108	1.033	1.187	1.021	1.276
40	2000	2.016	2.327	1.992	1.795	1.115	1.048	1.151	1.022	1.307
41	2001	1.992	2.345	1.993	1.787	1.116	1.023	1.108	1.022	1.383
42	2002	2.059	2.534	2.024	1.853	1.116	0.993	1.152	1.023	1.419
43	2003	1.797	2.380	1.737	1.636	1.117	1.014	1.399	1.005	1.028

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	2.115	2.803	1.887	1.839	1.118	1.020	1.257	1.017	1.262
45	2005	2.038	2.812	1.847	1.806	1.118	1.002	1.444	1.013	1.101
46	2006	2.194	3.006	2.019	1.925	1.119	1.014	1.310	1.018	1.274
47	2007	2.027	2.680	1.824	1.770	1.120	1.015	1.337	1.011	1.151
48	2008	2.066	2.734	1.798	1.865	1.120	1.017	1.489	1.007	1.092
49	2009	2.112	2.872	1.806	1.995	1.121	1.017	1.456	1.016	1.183
50	2010	2.190	2.825	1.844	2.036	1.122	1.047	1.635	1.004	1.056
51	2011	2.060	3.350	1.828	1.997	1.123	1.033	1.168	1.024	1.440
52	2012	2.207	3.520	1.918	2.111	1.123	1.017	1.200	1.028	1.498
53	2013	2.308	3.799	2.017	2.142	1.124	1.007	1.543	1.016	1.206
54	2014	2.336	3.603	1.967	2.169	1.125	1.011	1.458	1.020	1.283
55	2015	2.478	3.778	2.048	2.295	1.126	1.010	1.527	1.016	1.301
56	2016	2.480	3.665	2.024	2.323	1.126	1.018	1.718	1.016	1.161
57	2017	2.467	3.790	2.085	2.311	1.127	1.013	1.464	1.021	1.355
58	2018	2.428	3.546	2.048	2.239	1.128	1.009	1.492	1.019	1.295
59	2019	2.280	3.328	1.913	2.158	1.129	0.995	1.652	1.013	1.148
60	2020	2.266	3.086	1.816	2.231	1.130	1.014	1.859	1.004	1.043
61	2021	2.518	3.500	2.000	2.445	1.151	1.019	1.771	1.013	1.162

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Bangladesh

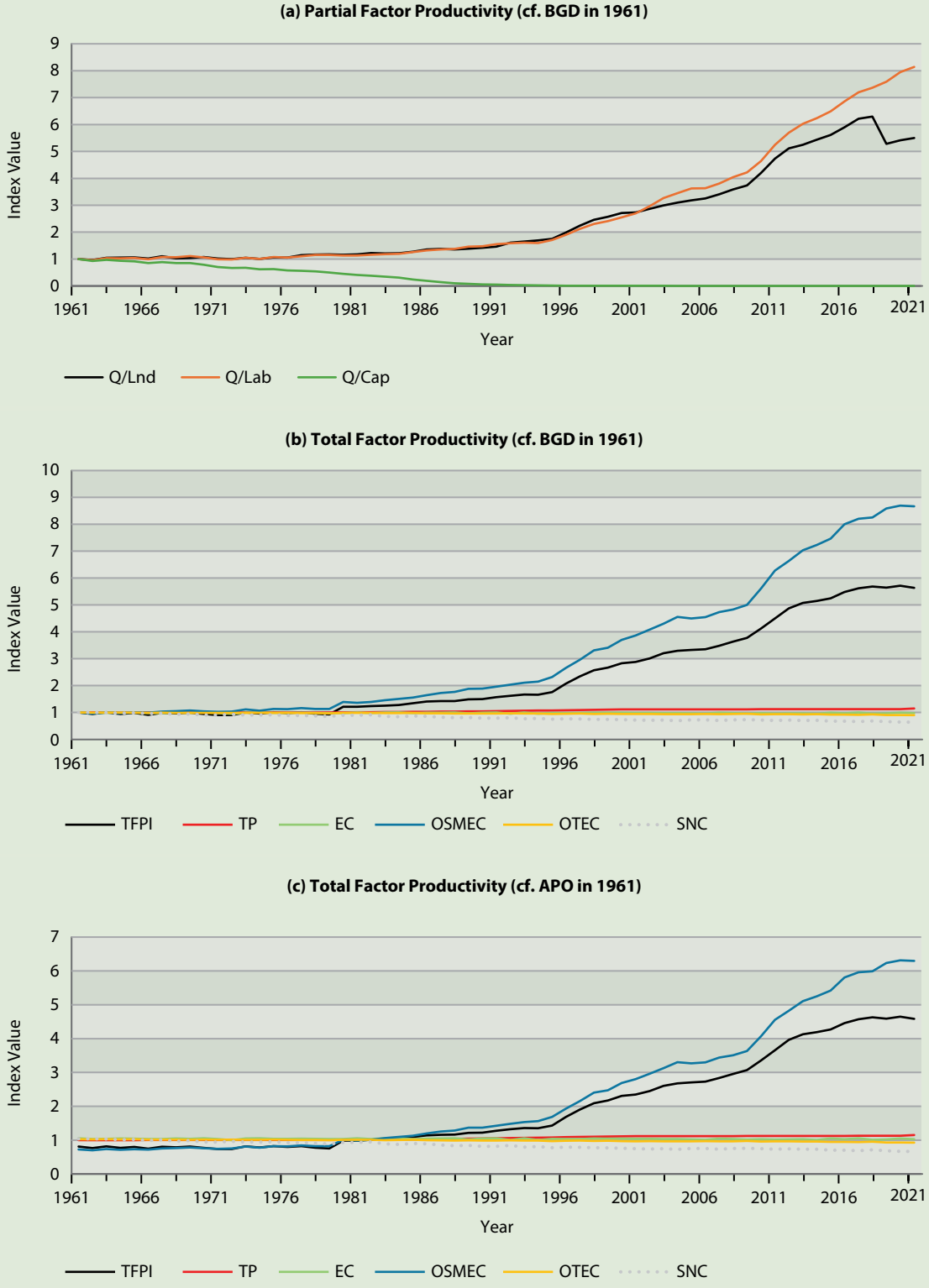
Bangladesh is one of the world's largest producers of rice (ranking fourth worldwide), fish (fifth), jute (second), tea (tenth), and tropical fruits (fifth). In 2022, its agriculture sector employed 29.7% (53.1%) of the male (female) labor force and contributed 11.2% to the country's GDP (FAO, 2025a, 2025b). Most land in Bangladesh is fertile but prone to flooding. Figure 8 reports the estimated changes in agricultural productivity in Bangladesh from 1961 to 2021. The index numbers used to construct this figure are shown in Table 12. Figure 8(a) indicates that land productivity increased at a slower rate than labor productivity over the sample period; in 2021, the output per unit of land (labor) was 5.498 (8.140) times higher than that in 1961. However, capital productivity decreased over the sample period and started collapsing at the beginning of the 1980s. In the absence of other explanations, this decline may have been attributed to the mismeasurement of capital input in the Bangladeshi economy. Figure 8(b) indicates that the TFP in Bangladeshi agriculture was more than five times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.977 \times 1.151 \times 8.674 \times 0.903 \times 0.640 \\ &= 5.639. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a small impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a more than eight-fold increase in TFP, (iv) lower technical efficiency (OTEC) led to a 9.7% fall in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 36% fall in measured TFP. In the case of Bangladesh, an important source of statistical noise is measurement errors (especially in the measurement of capital).

FIGURE 8

PRODUCTIVITY CHANGE IN BANGLADESH



Source: Authors' illustration.

TABLE 12

PRODUCTIVITY CHANGE IN BANGLADESH

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	0.966	0.959	0.930	0.944	1.000	0.980	0.963	0.997	1.002
3	1963	1.051	1.034	0.973	1.001	1.001	0.987	1.015	1.002	0.997
4	1964	1.056	1.027	0.937	0.945	1.001	0.996	0.980	0.996	0.972
5	1965	1.062	1.040	0.918	0.984	1.001	0.993	1.006	0.999	0.984
6	1966	1.021	0.993	0.849	0.918	1.002	0.978	0.992	0.991	0.953
7	1967	1.107	1.076	0.889	0.986	1.002	0.983	1.035	0.993	0.974
8	1968	1.029	1.071	0.856	0.968	1.002	1.000	1.052	0.989	0.930
9	1969	1.043	1.109	0.855	0.995	1.002	0.986	1.074	0.987	0.950
10	1970	1.077	1.061	0.787	0.946	1.003	1.002	1.047	0.991	0.908
11	1971	1.021	0.993	0.705	0.906	1.003	0.983	1.025	0.986	0.909
12	1972	1.001	0.986	0.669	0.908	1.003	0.950	1.036	0.989	0.929
13	1973	1.047	1.047	0.676	1.003	1.003	0.998	1.116	0.987	0.909
14	1974	1.007	1.008	0.618	0.963	1.004	1.004	1.067	0.985	0.909
15	1975	1.064	1.079	0.625	1.014	1.004	0.984	1.130	0.989	0.918
16	1976	1.059	1.057	0.576	0.982	1.004	0.988	1.127	0.986	0.891
17	1977	1.149	1.103	0.562	1.014	1.004	0.992	1.163	0.981	0.892
18	1978	1.169	1.153	0.546	0.958	1.004	0.988	1.131	0.978	0.872
19	1979	1.172	1.151	0.503	0.928	1.005	0.983	1.130	0.975	0.853
20	1980	1.159	1.132	0.453	1.212	1.005	0.982	1.391	0.985	0.896
21	1981	1.175	1.131	0.413	1.215	1.009	1.000	1.359	0.986	0.898
22	1982	1.225	1.162	0.384	1.243	1.013	0.979	1.393	0.985	0.913
23	1983	1.208	1.183	0.349	1.253	1.017	1.003	1.462	0.977	0.860
24	1984	1.220	1.198	0.313	1.282	1.022	1.007	1.511	0.978	0.843
25	1985	1.277	1.260	0.245	1.347	1.026	0.983	1.558	0.984	0.872
26	1986	1.354	1.325	0.189	1.406	1.030	0.992	1.646	0.975	0.858
27	1987	1.376	1.355	0.140	1.423	1.034	0.998	1.730	0.968	0.823
28	1988	1.356	1.375	0.102	1.428	1.039	1.000	1.768	0.965	0.806
29	1989	1.389	1.462	0.077	1.492	1.043	0.968	1.882	0.966	0.813
30	1990	1.418	1.480	0.061	1.502	1.047	0.998	1.887	0.964	0.789
31	1991	1.461	1.555	0.049	1.571	1.054	1.002	1.964	0.961	0.789
32	1992	1.610	1.586	0.038	1.625	1.061	0.954	2.039	0.970	0.812
33	1993	1.655	1.609	0.029	1.668	1.067	1.004	2.112	0.964	0.764
34	1994	1.692	1.600	0.021	1.662	1.074	0.956	2.154	0.963	0.781
35	1995	1.750	1.707	0.017	1.760	1.081	0.988	2.324	0.948	0.748
36	1996	1.992	1.907	0.013	2.074	1.087	0.978	2.659	0.957	0.766
37	1997	2.244	2.123	0.013	2.343	1.094	0.983	2.965	0.964	0.762
38	1998	2.459	2.304	0.012	2.569	1.101	0.995	3.309	0.951	0.746
39	1999	2.570	2.410	0.011	2.669	1.108	0.994	3.409	0.957	0.743
40	2000	2.716	2.548	0.010	2.834	1.115	0.993	3.703	0.945	0.732
41	2001	2.733	2.698	0.009	2.885	1.116	0.984	3.862	0.943	0.722
42	2002	2.867	2.968	0.008	3.015	1.116	0.988	4.082	0.944	0.710
43	2003	2.995	3.269	0.007	3.203	1.117	0.980	4.306	0.942	0.722

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	3.097	3.453	0.006	3.294	1.118	0.983	4.552	0.943	0.698
45	2005	3.182	3.628	0.005	3.328	1.118	0.969	4.503	0.942	0.724
46	2006	3.254	3.633	0.005	3.357	1.119	0.960	4.545	0.945	0.727
47	2007	3.408	3.806	0.004	3.485	1.120	0.992	4.736	0.939	0.706
48	2008	3.593	4.043	0.004	3.634	1.120	0.980	4.831	0.943	0.726
49	2009	3.741	4.219	0.004	3.777	1.121	0.963	5.007	0.952	0.734
50	2010	4.199	4.643	0.004	4.126	1.122	0.978	5.610	0.933	0.719
51	2011	4.734	5.247	0.004	4.499	1.123	0.967	6.278	0.940	0.703
52	2012	5.113	5.696	0.004	4.872	1.123	0.970	6.640	0.940	0.716
53	2013	5.249	6.028	0.004	5.074	1.124	0.974	7.033	0.933	0.706
54	2014	5.436	6.238	0.004	5.153	1.125	0.956	7.231	0.938	0.707
55	2015	5.613	6.486	0.004	5.251	1.126	0.998	7.467	0.926	0.676
56	2016	5.898	6.858	0.004	5.485	1.126	0.975	8.001	0.924	0.675
57	2017	6.215	7.194	0.004	5.624	1.127	1.002	8.207	0.918	0.661
58	2018	6.296	7.365	0.003	5.690	1.128	0.958	8.252	0.931	0.686
59	2019	5.280	7.592	0.003	5.642	1.129	0.971	8.589	0.908	0.660
60	2020	5.413	7.950	0.003	5.716	1.130	0.996	8.696	0.907	0.644
61	2021	5.498	8.140	0.003	5.639	1.151	0.977	8.674	0.903	0.640

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Cambodia

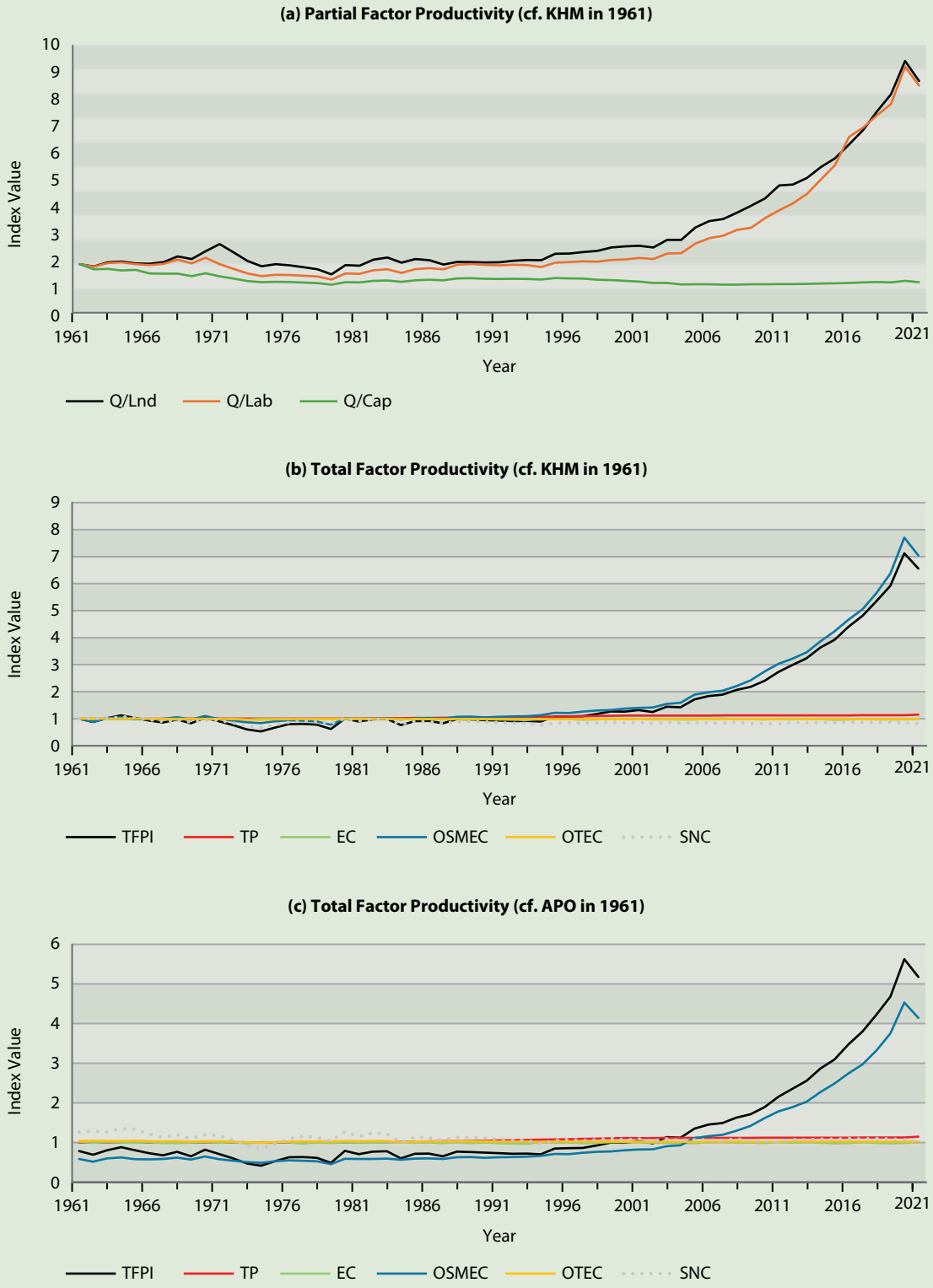
Agriculture is the most important sector in the Cambodian economy. In 2022, it employed 34.8% (39.6%) of the male (female) labor force and contributed 16.7% to the country's GDP (FAO, 2025a, 2025b). Rice is the largest agricultural industry. The structure of the sector has changed significantly since the government transformed the country's economic system from a planned system to a market-based one in 1995. Figure 9 reports the estimated changes in agricultural productivity in Cambodia from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 13. Figure 9(a) indicates that land and labor productivity increased steadily since the transition to a market-based economy in 1995; in 2021, the output per unit of land (labor) was 8.538 (8.350) times higher than that in 1961. However, capital productivity fell since the transition; in 2021, the output per unit of capital was 0.264 of that in 1961. Figure 9(b) indicates that the TFP in Cambodian agriculture was 6.557 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.996 \times 1.151 \times 7.040 \times 0.988 \times 0.822 \\ &= 6.557. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a small impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a seven-fold increase in TFP, (iv) lower technical efficiency (OTEC) led to a 1.2% fall in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 17.8% fall in measured TFP. In the case of Cambodia, measurement errors (especially in the measurement of capital) are an important source of statistical noise.

FIGURE 9

PRODUCTIVITY CHANGE IN CAMBODIA



Source: Authors' illustration.

TABLE 13

PRODUCTIVITY CHANGE IN CAMBODIA

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	0.909	0.899	0.788	0.882	1.000	0.979	0.881	1.006	1.017
3	1963	1.078	1.050	0.808	1.020	1.001	0.992	1.021	1.001	1.005
4	1964	1.112	1.083	0.748	1.120	1.001	0.983	1.063	1.002	1.069
5	1965	1.033	1.003	0.768	1.024	1.001	0.975	0.988	1.006	1.056
6	1966	1.015	0.965	0.620	0.930	1.002	0.992	0.980	0.996	0.959
7	1967	1.088	1.014	0.614	0.859	1.002	0.968	0.996	0.990	0.898
8	1968	1.324	1.190	0.610	0.970	1.002	0.969	1.060	0.997	0.945
9	1969	1.214	1.036	0.509	0.828	1.002	0.985	0.972	0.989	0.872
10	1970	1.531	1.267	0.629	1.038	1.003	0.991	1.104	0.996	0.950
11	1971	1.825	1.000	0.502	0.903	1.003	0.980	0.991	0.995	0.932
12	1972	1.489	0.810	0.409	0.763	1.003	0.989	0.927	0.984	0.842
13	1973	1.134	0.616	0.311	0.604	1.003	0.963	0.865	0.972	0.743
14	1974	0.915	0.511	0.257	0.529	1.004	0.995	0.834	0.957	0.664
15	1975	0.998	0.562	0.276	0.668	1.004	0.988	0.901	0.976	0.765
16	1976	0.951	0.558	0.266	0.800	1.004	0.990	0.942	0.985	0.867
17	1977	0.877	0.525	0.242	0.807	1.004	0.959	0.922	0.993	0.915
18	1978	0.794	0.497	0.221	0.782	1.004	0.985	0.896	0.992	0.889
19	1979	0.582	0.368	0.159	0.619	1.005	0.974	0.779	0.986	0.823
20	1980	0.962	0.622	0.263	1.005	1.005	0.991	1.004	1.000	1.007
21	1981	0.943	0.604	0.253	0.898	1.009	0.982	0.997	0.997	0.912
22	1982	1.186	0.752	0.315	0.980	1.013	0.980	0.997	1.001	0.989
23	1983	1.278	0.791	0.333	0.993	1.017	0.999	1.012	0.999	0.965
24	1984	1.067	0.642	0.272	0.765	1.022	0.993	0.967	0.978	0.797
25	1985	1.216	0.801	0.341	0.913	1.026	0.987	1.012	0.989	0.902
26	1986	1.163	0.837	0.361	0.919	1.030	0.987	1.025	0.991	0.889
27	1987	0.984	0.790	0.339	0.829	1.034	0.971	0.997	0.987	0.839
28	1988	1.095	0.976	0.415	0.981	1.039	0.995	1.070	0.990	0.896
29	1989	1.091	1.012	0.424	0.969	1.043	0.970	1.079	0.991	0.895
30	1990	1.070	0.974	0.403	0.945	1.047	0.982	1.051	0.993	0.881
31	1991	1.078	0.952	0.392	0.930	1.054	0.969	1.070	0.988	0.862
32	1992	1.140	0.978	0.398	0.913	1.061	0.961	1.086	0.985	0.838
33	1993	1.176	0.965	0.395	0.918	1.067	0.950	1.095	0.985	0.840
34	1994	1.163	0.888	0.372	0.895	1.074	0.991	1.129	0.973	0.766
35	1995	1.432	1.066	0.435	1.078	1.081	0.984	1.217	0.991	0.840
36	1996	1.438	1.084	0.416	1.087	1.087	0.986	1.208	0.985	0.852
37	1997	1.499	1.116	0.407	1.096	1.094	0.963	1.260	0.986	0.838
38	1998	1.551	1.104	0.363	1.174	1.101	0.976	1.308	0.988	0.846
39	1999	1.692	1.173	0.348	1.267	1.108	0.992	1.322	0.987	0.884
40	2000	1.736	1.195	0.317	1.265	1.115	0.995	1.373	0.986	0.842
41	2001	1.754	1.259	0.280	1.317	1.116	0.986	1.401	0.982	0.870
42	2002	1.690	1.216	0.228	1.244	1.116	0.979	1.414	0.980	0.822
43	2003	2.003	1.439	0.227	1.443	1.117	0.976	1.549	0.987	0.866

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	1.996	1.452	0.170	1.423	1.118	0.969	1.591	0.984	0.840
45	2005	2.503	1.846	0.175	1.713	1.118	0.971	1.891	0.981	0.851
46	2006	2.772	2.074	0.178	1.841	1.119	0.993	1.980	0.988	0.846
47	2007	2.854	2.169	0.162	1.893	1.120	1.006	2.037	0.985	0.838
48	2008	3.119	2.415	0.162	2.063	1.120	0.979	2.209	0.986	0.864
49	2009	3.404	2.502	0.177	2.173	1.121	0.983	2.420	0.983	0.829
50	2010	3.711	2.900	0.176	2.402	1.122	0.970	2.745	0.983	0.818
51	2011	4.235	3.214	0.185	2.735	1.123	1.002	3.035	0.982	0.816
52	2012	4.280	3.504	0.184	2.989	1.123	0.976	3.223	0.989	0.855
53	2013	4.549	3.895	0.193	3.237	1.124	0.999	3.454	0.989	0.844
54	2014	5.002	4.493	0.205	3.637	1.125	0.981	3.869	0.989	0.862
55	2015	5.353	5.073	0.213	3.920	1.126	0.963	4.230	0.991	0.863
56	2016	5.920	6.235	0.233	4.401	1.126	0.968	4.665	0.989	0.875
57	2017	6.519	6.617	0.249	4.813	1.127	0.993	5.049	0.985	0.864
58	2018	7.279	7.124	0.265	5.350	1.128	0.974	5.652	0.987	0.873
59	2019	7.986	7.583	0.254	5.924	1.129	0.966	6.377	0.985	0.865
60	2020	9.355	9.121	0.318	7.124	1.130	0.975	7.704	0.988	0.850
61	2021	8.538	8.350	0.264	6.557	1.151	0.996	7.040	0.988	0.822

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

China

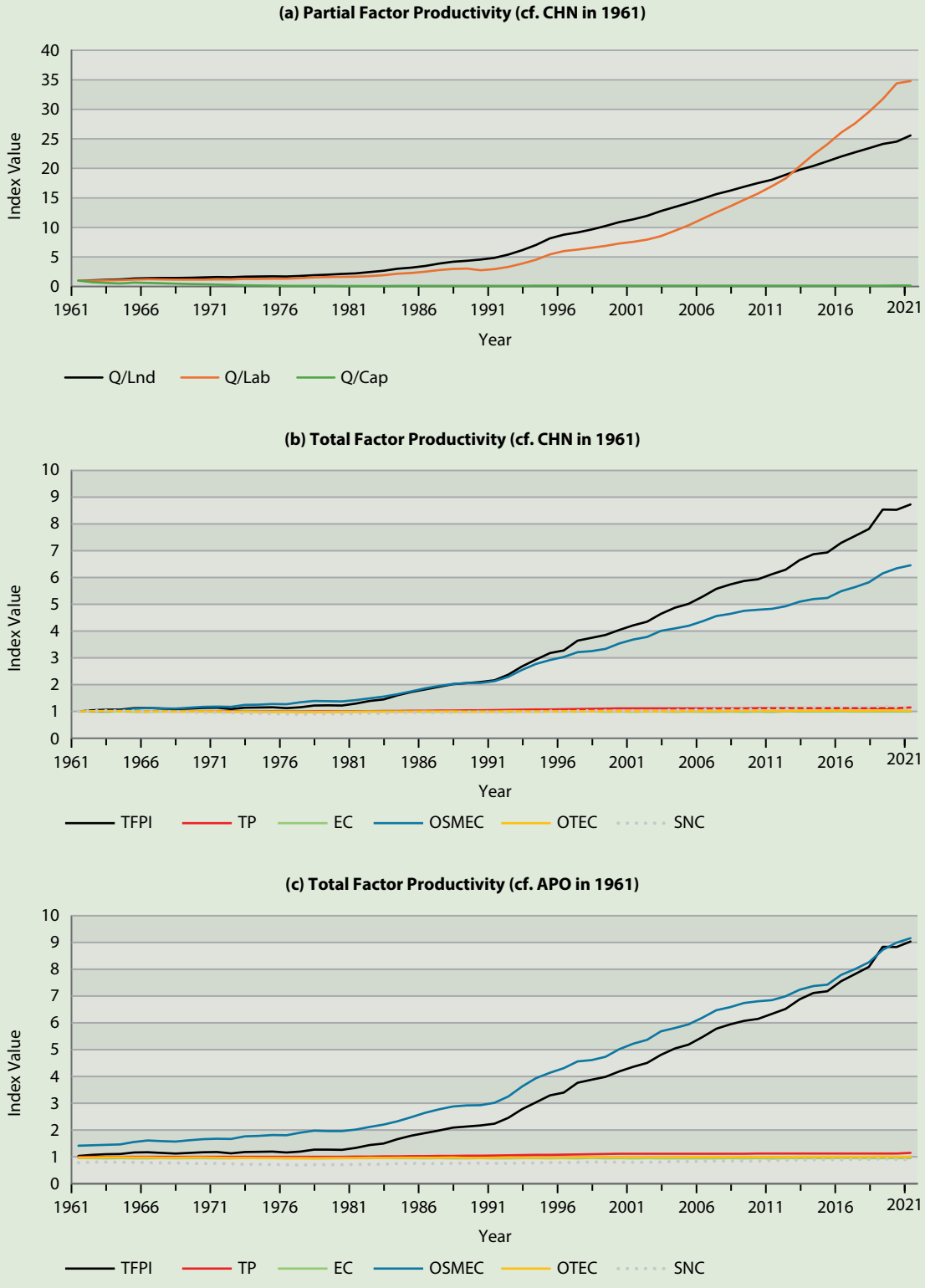
China is the world's largest producer and consumer of agricultural products. In 2020, its agriculture sector employed 23.6% of the labor force and contributed 8% to the country's GDP (FAO, 2025a, 2025b). Approximately 75% of the arable land area is used for food crops, with the most important crop being rice. Figure 10 reports the estimated changes in agricultural productivity in China from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 14. Figure 10(a) indicates that land and labor productivity increased significantly over the sample period; in 2021, the output per unit of land (labor) was 25.575 (34.791) times higher than that in 1961. However, capital productivity fell significantly over the sample period; in 2021, the output per unit of capital was 15.7% of that in 1961. Figure 10(b) indicates that the TFP in Chinese agriculture was 8.730 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.999 \times 1.151 \times 6.459 \times 1.029 \times 1.142 \\ &= 8.730. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had almost no impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) increased TFP by a factor of 6.459, (iv) improvements in technical efficiency (OTEC) led to a 2.9% increase in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 14.2% increase in measured TFP.

FIGURE 10

PRODUCTIVITY CHANGE IN CHINA



Source: Authors' illustration.

TABLE 14

PRODUCTIVITY CHANGE IN CHINA

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.055	0.976	0.728	1.041	1.000	0.994	1.009	1.008	1.029
3	1963	1.142	1.028	0.604	1.067	1.001	0.989	1.021	1.019	1.036
4	1964	1.210	1.080	0.500	1.068	1.001	1.000	1.035	1.012	1.018
5	1965	1.346	1.168	0.660	1.126	1.001	0.991	1.098	1.010	1.023
6	1966	1.414	1.214	0.620	1.134	1.002	0.988	1.136	1.005	1.004
7	1967	1.439	1.195	0.548	1.109	1.002	0.994	1.120	1.002	0.993
8	1968	1.463	1.161	0.476	1.091	1.002	0.992	1.111	0.997	0.991
9	1969	1.487	1.172	0.427	1.108	1.002	0.995	1.142	1.004	0.968
10	1970	1.537	1.152	0.393	1.131	1.003	0.999	1.173	1.004	0.959
11	1971	1.598	1.208	0.320	1.145	1.003	0.991	1.186	1.001	0.971
12	1972	1.575	1.204	0.248	1.097	1.003	0.990	1.175	0.987	0.952
13	1973	1.676	1.294	0.205	1.142	1.003	1.003	1.248	0.987	0.922
14	1974	1.682	1.304	0.168	1.150	1.004	0.995	1.259	0.984	0.929
15	1975	1.716	1.317	0.138	1.155	1.004	0.998	1.283	0.979	0.917
16	1976	1.702	1.320	0.118	1.128	1.004	0.992	1.273	0.984	0.903
17	1977	1.778	1.410	0.105	1.161	1.004	0.994	1.343	0.972	0.891
18	1978	1.911	1.546	0.099	1.225	1.004	0.987	1.396	0.977	0.906
19	1979	2.006	1.595	0.091	1.232	1.005	0.991	1.386	0.981	0.911
20	1980	2.122	1.626	0.085	1.224	1.005	0.995	1.382	0.982	0.903
21	1981	2.240	1.670	0.084	1.295	1.009	0.995	1.424	0.985	0.920
22	1982	2.460	1.770	0.087	1.392	1.013	0.993	1.493	0.995	0.932
23	1983	2.675	1.906	0.087	1.451	1.017	1.002	1.554	0.989	0.926
24	1984	2.999	2.164	0.091	1.606	1.022	0.994	1.645	0.999	0.962
25	1985	3.207	2.300	0.091	1.728	1.026	0.995	1.752	0.999	0.967
26	1986	3.480	2.510	0.091	1.822	1.030	0.986	1.867	1.001	0.960
27	1987	3.889	2.782	0.094	1.921	1.034	0.995	1.959	0.995	0.958
28	1988	4.182	2.964	0.095	2.023	1.039	0.990	2.032	1.003	0.966
29	1989	4.344	3.027	0.095	2.062	1.043	0.992	2.062	0.991	0.975
30	1990	4.567	2.764	0.099	2.099	1.047	0.999	2.069	0.993	0.977
31	1991	4.845	2.949	0.104	2.164	1.054	0.992	2.131	0.998	0.974
32	1992	5.402	3.309	0.112	2.375	1.061	0.991	2.297	1.009	0.974
33	1993	6.169	3.866	0.121	2.691	1.067	0.999	2.558	1.000	0.987
34	1994	7.029	4.542	0.131	2.936	1.074	0.996	2.777	0.997	0.991
35	1995	8.150	5.431	0.142	3.185	1.081	0.993	2.919	1.001	1.017
36	1996	8.781	6.000	0.144	3.284	1.087	0.995	3.040	1.001	0.997
37	1997	9.156	6.265	0.138	3.642	1.094	0.992	3.219	1.015	1.027
38	1998	9.655	6.562	0.135	3.749	1.101	1.002	3.254	1.012	1.032
39	1999	10.249	6.873	0.133	3.854	1.108	0.991	3.340	1.013	1.037
40	2000	10.915	7.282	0.132	4.048	1.115	0.993	3.538	1.014	1.018
41	2001	11.365	7.552	0.132	4.214	1.116	0.989	3.685	1.011	1.025
42	2002	11.974	7.932	0.133	4.351	1.116	0.997	3.788	1.011	1.021
43	2003	12.761	8.529	0.136	4.646	1.117	0.992	4.010	1.013	1.032

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	13.461	9.444	0.136	4.871	1.118	0.987	4.097	1.015	1.061
45	2005	14.131	10.374	0.135	5.018	1.118	0.992	4.195	1.019	1.057
46	2006	14.858	11.477	0.134	5.288	1.119	0.987	4.370	1.021	1.073
47	2007	15.632	12.564	0.134	5.584	1.120	0.988	4.566	1.022	1.082
48	2008	16.248	13.569	0.131	5.741	1.120	0.994	4.646	1.020	1.088
49	2009	16.879	14.668	0.129	5.873	1.121	0.986	4.757	1.026	1.089
50	2010	17.528	15.726	0.126	5.937	1.122	0.999	4.803	1.025	1.077
51	2011	18.064	16.981	0.123	6.123	1.123	0.982	4.830	1.027	1.120
52	2012	18.919	18.298	0.122	6.299	1.123	1.000	4.930	1.023	1.111
53	2013	19.749	20.346	0.126	6.651	1.124	0.994	5.102	1.035	1.127
54	2014	20.417	22.364	0.125	6.874	1.125	0.994	5.202	1.030	1.147
55	2015	21.185	24.069	0.125	6.942	1.126	0.997	5.236	1.035	1.141
56	2016	22.006	26.067	0.149	7.299	1.126	1.003	5.492	1.034	1.138
57	2017	22.723	27.621	0.151	7.557	1.127	0.995	5.649	1.028	1.160
58	2018	23.412	29.555	0.152	7.819	1.128	0.998	5.825	1.030	1.158
59	2019	24.117	31.729	0.153	8.538	1.129	0.994	6.155	1.042	1.187
60	2020	24.549	34.406	0.153	8.534	1.130	0.999	6.343	1.033	1.154
61	2021	25.575	34.791	0.157	8.730	1.151	0.999	6.459	1.029	1.142

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Fiji

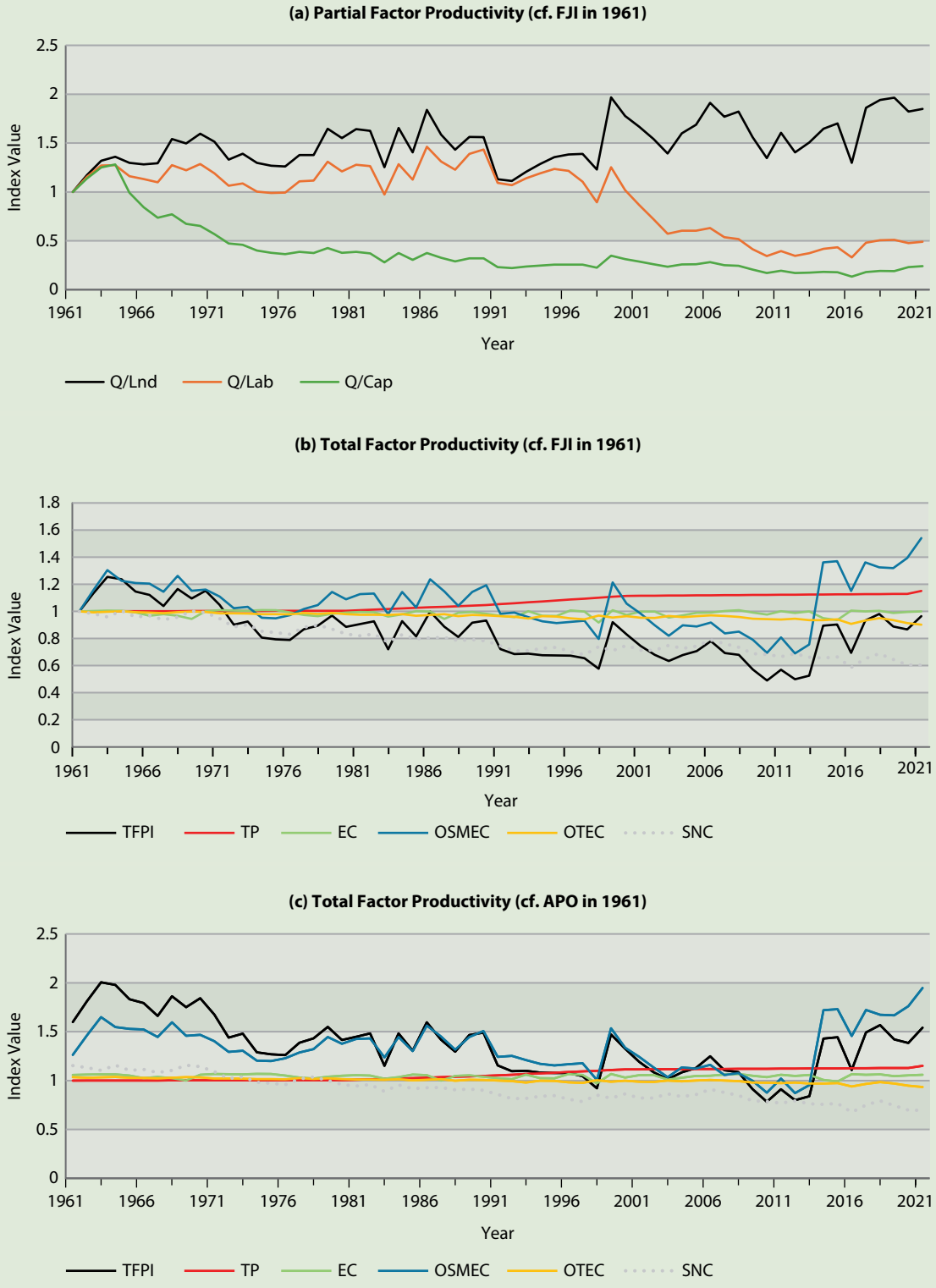
Fiji's agriculture sector is diverse and historically significant, playing a central role in rural livelihoods, food security and exports. In 2016, it employed 35.3% (21.1%) of the male (female) labor force and contributed 10.7% to the country's GDP (FAO, 2025a, 2025b). While sugarcane dominated the industry for much of the 20th century, this sector is now more diversified and includes high-value niche crops like kava, turmeric, vanilla, and organic fruits and vegetables. Figure 11 reports the estimated changes in agricultural productivity in Fiji from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 15. Figure 11(a) indicates that land productivity increased by a factor of 1.849 compared to 1961. Further, labor productivity and capital productivity decreased by more than 50% and 75%, respectively. Figure 11(b) indicates that the TFP in Fiji's agriculture was 3.5% lower in 2021 than in 1961. The breakdown of this decrease is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 1 \times 1.151 \times 1.541 \times 0.902 \times 0.603 \\ &= 0.965. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had no impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a 54.1% increase in TFP, (iv) changes in technical efficiency (OTEC) led to a 9.8% fall in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for almost a 40% decrease in measured TFP. These results reveal that the effect of statistical noise is substantial.

FIGURE 11

PRODUCTIVITY CHANGE IN FIJI



Source: Authors' illustration.

TABLE 15

PRODUCTIVITY CHANGE IN FIJI

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.172	1.155	1.138	1.134	1.000	1.003	1.157	0.993	0.983
3	1963	1.320	1.271	1.251	1.255	1.001	1.006	1.304	0.997	0.959
4	1964	1.360	1.274	1.281	1.238	1.001	1.004	1.225	1.001	1.004
5	1965	1.298	1.161	0.992	1.146	1.001	0.993	1.210	0.994	0.959
6	1966	1.282	1.131	0.843	1.122	1.002	0.969	1.205	0.991	0.968
7	1967	1.295	1.098	0.737	1.040	1.002	0.980	1.145	0.987	0.938
8	1968	1.542	1.274	0.770	1.165	1.002	0.968	1.262	0.994	0.958
9	1969	1.497	1.222	0.674	1.095	1.002	0.945	1.153	0.999	1.004
10	1970	1.595	1.286	0.653	1.153	1.003	1.002	1.162	0.996	0.991
11	1971	1.515	1.191	0.568	1.048	1.003	1.009	1.110	0.986	0.947
12	1972	1.331	1.063	0.473	0.901	1.003	1.006	1.024	0.985	0.885
13	1973	1.391	1.086	0.459	0.926	1.003	1.005	1.034	0.984	0.903
14	1974	1.298	1.003	0.400	0.807	1.004	1.010	0.953	0.980	0.853
15	1975	1.268	0.989	0.377	0.794	1.004	1.009	0.949	0.980	0.843
16	1976	1.261	0.994	0.364	0.789	1.004	0.993	0.972	0.978	0.832
17	1977	1.378	1.109	0.387	0.868	1.004	0.973	1.018	0.989	0.883
18	1978	1.377	1.117	0.376	0.895	1.004	0.965	1.046	0.981	0.900
19	1979	1.646	1.309	0.426	0.969	1.005	0.982	1.144	0.988	0.869
20	1980	1.551	1.210	0.378	0.886	1.005	0.992	1.089	0.980	0.833
21	1981	1.642	1.279	0.387	0.906	1.009	0.996	1.128	0.975	0.819
22	1982	1.625	1.264	0.372	0.928	1.013	0.994	1.132	0.975	0.834
23	1983	1.253	0.974	0.279	0.721	1.017	0.962	0.979	0.974	0.772
24	1984	1.654	1.283	0.375	0.928	1.022	0.979	1.143	0.979	0.829
25	1985	1.405	1.126	0.304	0.816	1.026	1.002	1.030	0.968	0.796
26	1986	1.839	1.462	0.376	0.999	1.030	0.998	1.238	0.974	0.805
27	1987	1.586	1.311	0.326	0.887	1.034	0.945	1.147	0.980	0.808
28	1988	1.432	1.228	0.290	0.811	1.039	0.990	1.040	0.965	0.785
29	1989	1.563	1.389	0.320	0.917	1.043	0.996	1.144	0.974	0.792
30	1990	1.561	1.433	0.320	0.933	1.047	0.982	1.193	0.971	0.782
31	1991	1.130	1.093	0.231	0.723	1.054	0.968	0.983	0.966	0.746
32	1992	1.112	1.069	0.221	0.686	1.061	0.958	0.991	0.961	0.709
33	1993	1.207	1.140	0.237	0.689	1.067	1.002	0.958	0.947	0.710
34	1994	1.285	1.190	0.247	0.677	1.074	0.968	0.926	0.965	0.728
35	1995	1.356	1.234	0.257	0.675	1.081	0.967	0.913	0.962	0.735
36	1996	1.382	1.217	0.256	0.674	1.087	1.008	0.923	0.948	0.703
37	1997	1.388	1.105	0.257	0.654	1.094	0.999	0.931	0.942	0.682
38	1998	1.230	0.893	0.225	0.577	1.101	0.918	0.797	0.969	0.740
39	1999	1.967	1.253	0.349	0.921	1.108	1.009	1.214	0.954	0.711
40	2000	1.777	1.019	0.313	0.830	1.115	0.973	1.057	0.964	0.750
41	2001	1.665	0.864	0.288	0.746	1.116	0.998	0.984	0.954	0.714
42	2002	1.540	0.720	0.260	0.680	1.116	0.999	0.897	0.952	0.714
43	2003	1.392	0.573	0.235	0.634	1.117	0.955	0.820	0.966	0.750

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	1.600	0.604	0.258	0.678	1.118	0.971	0.898	0.957	0.726
45	2005	1.688	0.603	0.260	0.707	1.118	0.990	0.889	0.965	0.744
46	2006	1.912	0.631	0.281	0.781	1.119	0.991	0.918	0.971	0.790
47	2007	1.769	0.536	0.250	0.692	1.120	1.003	0.837	0.966	0.762
48	2008	1.822	0.518	0.245	0.679	1.120	1.008	0.851	0.960	0.736
49	2009	1.560	0.414	0.206	0.572	1.121	0.991	0.790	0.946	0.688
50	2010	1.347	0.345	0.170	0.490	1.122	0.977	0.695	0.944	0.683
51	2011	1.605	0.395	0.195	0.570	1.123	1.001	0.808	0.940	0.667
52	2012	1.405	0.346	0.170	0.500	1.123	0.989	0.690	0.946	0.689
53	2013	1.506	0.373	0.175	0.526	1.124	1.000	0.755	0.936	0.661
54	2014	1.647	0.419	0.182	0.895	1.125	0.950	1.362	0.936	0.657
55	2015	1.702	0.434	0.179	0.904	1.126	0.936	1.370	0.941	0.665
56	2016	1.298	0.330	0.134	0.694	1.126	1.006	1.151	0.907	0.586
57	2017	1.861	0.480	0.180	0.933	1.127	1.001	1.362	0.932	0.652
58	2018	1.941	0.505	0.191	0.981	1.128	1.005	1.325	0.950	0.688
59	2019	1.965	0.510	0.189	0.890	1.129	0.988	1.319	0.936	0.646
60	2020	1.821	0.477	0.231	0.867	1.130	0.995	1.393	0.914	0.605
61	2021	1.849	0.489	0.241	0.965	1.151	1.000	1.541	0.902	0.603

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

France

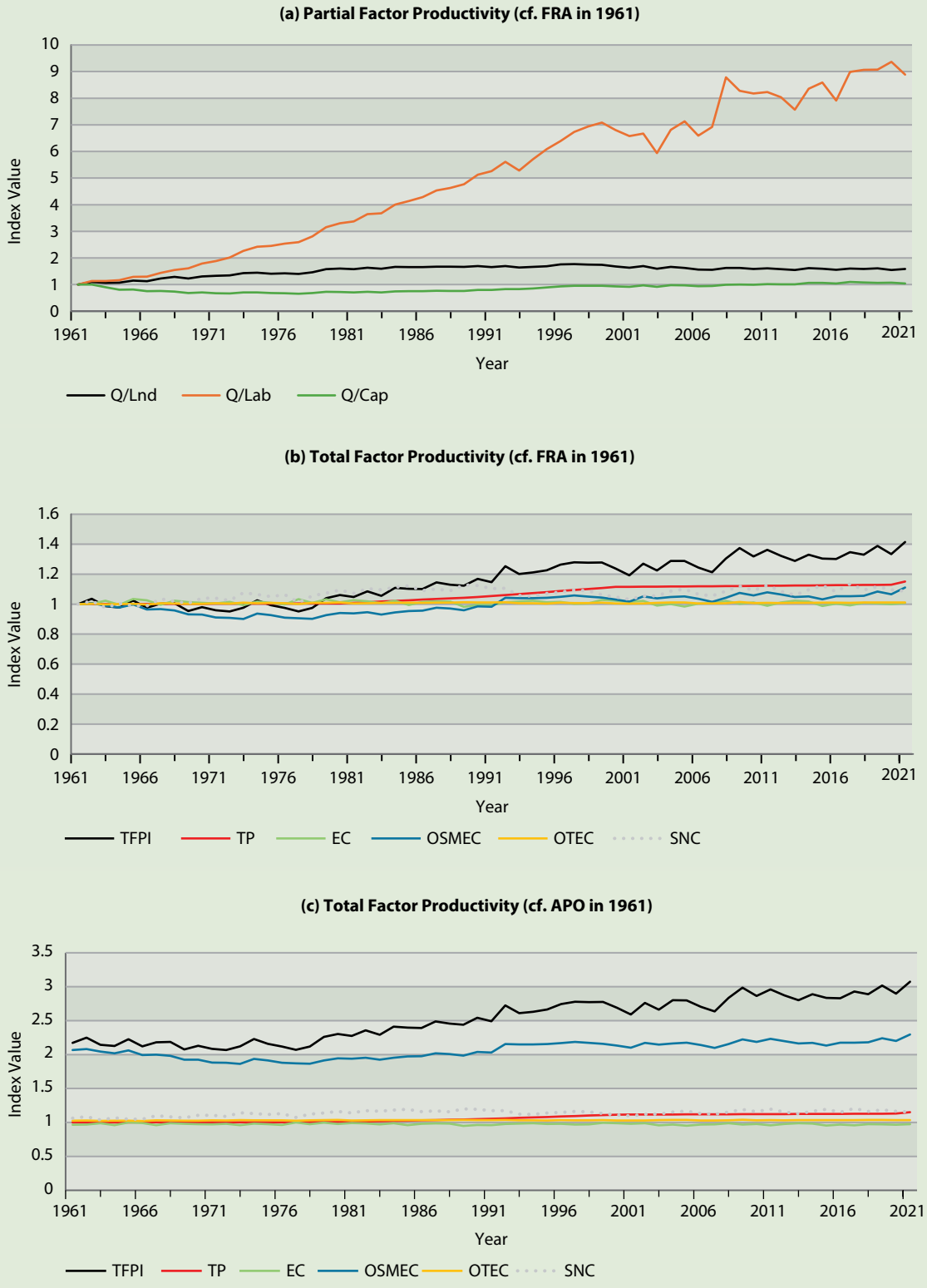
France is the world's sixth largest producer and second largest exporter of agricultural products. In 2021, its agriculture sector employed 3.4% (1.4%) of the male (female) labor force and contributed 1.5% to the country's GDP (FAO, 2025a, 2025b). The main cereal crop is wheat. France has a reputation for producing high quality cheese and wine. Figure 12 reports the estimated changes in agricultural productivity in France from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 16. Figure 12(a) indicates stable land and capital productivities. On the contrary, labor productivity increased by a factor of 8.883 over the reference period. Figure 12(b) indicates that the TFP in French agriculture was 41.5% higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 1.007 \times 1.151 \times 1.111 \times 1.011 \times 1.087 \\ &= 1.415. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had almost no impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) higher scale-mix efficiency (OSMEC) led to a 11.1% increase in TFP, (iv) changes in technical efficiency (OTEC) had a negligible effect on TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for an 8.7% increase in measured TFP.

FIGURE 12

PRODUCTIVITY CHANGE IN FRANCE



Source: Authors' illustration.

TABLE 16

PRODUCTIVITY CHANGE IN FRANCE

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.094	1.132	1.004	1.035	1.000	1.003	1.007	1.003	1.022
3	1963	1.061	1.135	0.898	0.986	1.001	1.022	0.989	0.998	0.976
4	1964	1.070	1.169	0.808	0.978	1.001	0.995	0.977	1.001	1.005
5	1965	1.148	1.287	0.816	1.024	1.001	1.035	0.998	1.003	0.988
6	1966	1.128	1.295	0.749	0.976	1.002	1.026	0.965	0.997	0.988
7	1967	1.224	1.435	0.758	1.004	1.002	0.995	0.967	1.006	1.035
8	1968	1.289	1.547	0.733	1.006	1.002	1.023	0.958	1.005	1.019
9	1969	1.230	1.613	0.679	0.955	1.002	1.014	0.932	1.002	1.007
10	1970	1.306	1.788	0.702	0.980	1.003	1.009	0.931	1.002	1.039
11	1971	1.328	1.883	0.675	0.959	1.003	1.004	0.911	1.006	1.039
12	1972	1.348	2.016	0.667	0.951	1.003	1.016	0.909	1.003	1.024
13	1973	1.433	2.268	0.704	0.977	1.003	0.993	0.901	1.010	1.076
14	1974	1.449	2.420	0.709	1.025	1.004	1.018	0.937	1.006	1.064
15	1975	1.407	2.451	0.678	0.993	1.004	1.008	0.926	1.008	1.050
16	1976	1.421	2.537	0.674	0.975	1.004	0.998	0.909	1.006	1.064
17	1977	1.398	2.594	0.655	0.952	1.004	1.034	0.905	1.001	1.011
18	1978	1.460	2.809	0.682	0.974	1.004	1.009	0.903	1.008	1.056
19	1979	1.580	3.154	0.731	1.040	1.005	1.032	0.926	1.009	1.073
20	1980	1.606	3.302	0.720	1.060	1.005	1.012	0.941	1.011	1.095
21	1981	1.575	3.372	0.703	1.047	1.009	1.026	0.938	1.005	1.072
22	1982	1.633	3.644	0.727	1.085	1.013	1.020	0.946	1.006	1.104
23	1983	1.593	3.680	0.709	1.055	1.017	1.006	0.931	1.009	1.096
24	1984	1.667	4.005	0.748	1.109	1.022	1.022	0.945	1.009	1.113
25	1985	1.655	4.138	0.750	1.103	1.026	0.994	0.954	1.009	1.123
26	1986	1.654	4.285	0.750	1.101	1.030	1.015	0.957	1.009	1.091
27	1987	1.671	4.535	0.766	1.145	1.034	1.019	0.977	1.010	1.101
28	1988	1.674	4.627	0.761	1.130	1.039	1.018	0.971	1.010	1.089
29	1989	1.661	4.766	0.762	1.123	1.043	0.982	0.960	1.013	1.128
30	1990	1.699	5.130	0.799	1.169	1.047	0.996	0.986	1.011	1.124
31	1991	1.658	5.256	0.796	1.146	1.054	0.993	0.982	1.011	1.103
32	1992	1.693	5.613	0.830	1.254	1.061	1.012	1.043	1.012	1.106
33	1993	1.638	5.282	0.826	1.201	1.067	1.017	1.040	1.006	1.058
34	1994	1.661	5.708	0.856	1.211	1.074	1.023	1.040	1.006	1.054
35	1995	1.691	6.088	0.890	1.226	1.081	1.012	1.042	1.003	1.072
36	1996	1.757	6.394	0.935	1.263	1.087	1.015	1.049	1.010	1.080
37	1997	1.768	6.734	0.951	1.279	1.094	1.002	1.058	1.007	1.095
38	1998	1.753	6.936	0.953	1.276	1.101	1.005	1.051	1.007	1.089
39	1999	1.741	7.084	0.956	1.278	1.108	1.028	1.044	1.010	1.064
40	2000	1.679	6.805	0.932	1.237	1.115	1.023	1.031	1.004	1.047
41	2001	1.634	6.575	0.918	1.192	1.116	1.015	1.016	1.004	1.032
42	2002	1.697	6.673	0.967	1.270	1.116	1.022	1.051	1.005	1.055
43	2003	1.591	5.937	0.919	1.225	1.117	0.991	1.039	1.009	1.056

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	1.668	6.810	0.978	1.289	1.118	1.001	1.048	1.011	1.087
45	2005	1.627	7.130	0.967	1.288	1.118	0.985	1.052	1.011	1.100
46	2006	1.560	6.595	0.937	1.244	1.119	1.003	1.036	1.004	1.065
47	2007	1.558	6.918	0.943	1.213	1.120	1.007	1.016	1.005	1.055
48	2008	1.626	8.788	0.995	1.304	1.120	1.022	1.042	1.006	1.087
49	2009	1.625	8.281	1.005	1.374	1.121	1.002	1.075	1.015	1.121
50	2010	1.588	8.179	0.995	1.318	1.122	1.011	1.058	1.007	1.091
51	2011	1.610	8.231	1.020	1.362	1.123	0.990	1.079	1.009	1.126
52	2012	1.578	8.040	1.013	1.322	1.123	1.011	1.064	1.008	1.085
53	2013	1.550	7.570	1.007	1.288	1.124	1.023	1.047	1.008	1.061
54	2014	1.615	8.355	1.063	1.330	1.125	1.018	1.051	1.009	1.096
55	2015	1.594	8.592	1.067	1.304	1.126	0.988	1.032	1.011	1.125
56	2016	1.552	7.911	1.044	1.302	1.126	1.004	1.053	1.011	1.083
57	2017	1.605	8.986	1.099	1.347	1.127	0.991	1.053	1.009	1.135
58	2018	1.584	9.069	1.081	1.330	1.128	1.009	1.055	1.011	1.095
59	2019	1.606	9.078	1.060	1.389	1.129	1.005	1.084	1.012	1.117
60	2020	1.549	9.367	1.074	1.334	1.130	1.000	1.065	1.011	1.096
61	2021	1.587	8.883	1.038	1.415	1.151	1.007	1.111	1.011	1.087

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Germany

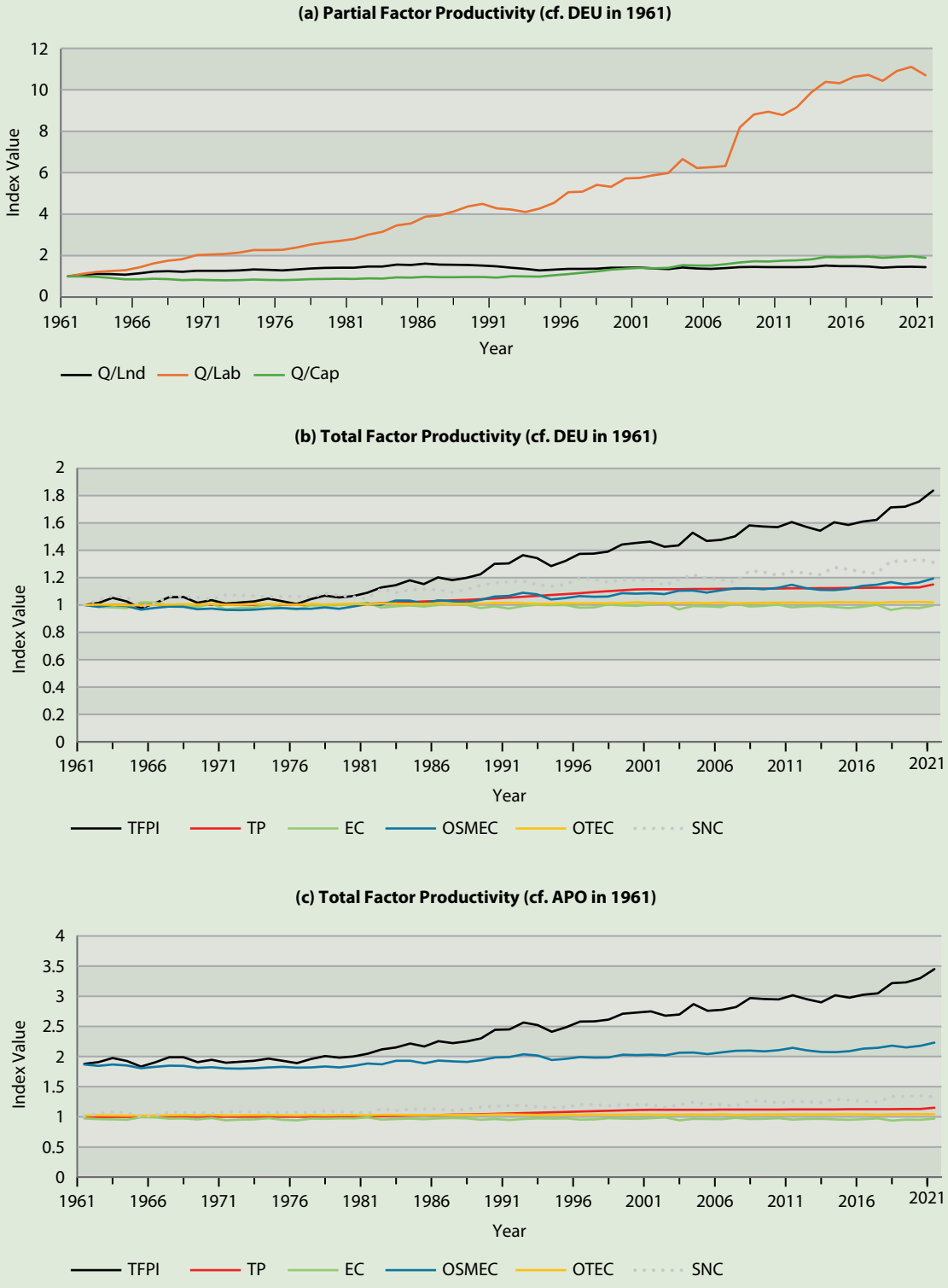
Agriculture is a small but politically important sector of the German economy. In 2021, its agriculture sector employed 1.5% (0.9%) of the male (female) labor force and contributed 0.7% to the country's GDP (FAO, 2025a, 2025b). The main agricultural products are potatoes and grains. Figure 13 reports the estimated changes in agricultural productivity in Germany from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 17. Figure 13(a) indicates that both land and labor productivity increased over the sample period; in 2021, the output per unit of land (labor) was 44.7% (1070.0%) higher than that in 1961. Capital productivity also increased over the sample period; in 2021, the output per unit of capital was 89.6% higher than that in 1961. Figure 13(b) indicates that the TFP in German agriculture was 83.8% higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.998 \times 1.151 \times 1.194 \times 1.020 \times 1.313 \\ &= 1.838. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had almost no impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a 19.4% increase in TFP, (iv) changes in technical efficiency (OTEC) led to a 2% rise in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 31.3% increase in measured TFP.

FIGURE 13

PRODUCTIVITY CHANGE IN GERMANY



Source: Authors' illustration.

TABLE 17

PRODUCTIVITY CHANGE IN GERMANY

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.071	1.115	0.996	1.016	1.000	0.987	0.987	1.003	1.039
3	1963	1.116	1.211	0.977	1.053	1.001	0.983	1.000	1.002	1.067
4	1964	1.108	1.261	0.921	1.027	1.001	0.978	0.992	0.999	1.059
5	1965	1.084	1.296	0.854	0.977	1.001	1.020	0.967	0.999	0.990
6	1966	1.142	1.439	0.856	1.013	1.002	1.018	0.980	1.002	1.012
7	1967	1.227	1.623	0.881	1.058	1.002	0.998	0.990	1.004	1.066
8	1968	1.248	1.751	0.868	1.060	1.002	1.001	0.988	1.007	1.061
9	1969	1.221	1.827	0.818	1.016	1.002	0.986	0.970	1.003	1.056
10	1970	1.271	2.026	0.834	1.037	1.003	1.008	0.975	1.010	1.042
11	1971	1.270	2.051	0.815	1.011	1.003	0.969	0.964	1.003	1.076
12	1972	1.265	2.077	0.809	1.019	1.003	0.980	0.963	1.005	1.071
13	1973	1.286	2.144	0.820	1.027	1.003	0.983	0.967	1.009	1.067
14	1974	1.334	2.264	0.848	1.048	1.004	1.003	0.975	1.008	1.060
15	1975	1.310	2.266	0.828	1.028	1.004	0.979	0.978	1.006	1.063
16	1976	1.289	2.278	0.819	1.007	1.004	0.967	0.973	1.003	1.063
17	1977	1.329	2.392	0.838	1.044	1.004	0.999	0.974	1.009	1.059
18	1978	1.381	2.538	0.868	1.069	1.004	0.994	0.983	1.004	1.084
19	1979	1.405	2.632	0.876	1.056	1.005	1.000	0.973	1.007	1.072
20	1980	1.416	2.705	0.879	1.066	1.005	1.002	0.989	1.010	1.060
21	1981	1.417	2.799	0.877	1.091	1.009	1.018	1.008	1.006	1.046
22	1982	1.472	3.006	0.905	1.129	1.013	0.982	1.002	1.012	1.120
23	1983	1.475	3.147	0.898	1.145	1.017	0.991	1.033	1.010	1.090
24	1984	1.563	3.456	0.951	1.181	1.022	0.997	1.034	1.009	1.112
25	1985	1.550	3.554	0.941	1.154	1.026	0.989	1.011	1.008	1.116
26	1986	1.613	3.874	0.979	1.202	1.030	1.001	1.035	1.012	1.113
27	1987	1.566	3.946	0.955	1.183	1.034	1.010	1.028	1.007	1.094
28	1988	1.557	4.131	0.961	1.199	1.039	1.003	1.022	1.010	1.115
29	1989	1.549	4.378	0.970	1.225	1.043	0.977	1.039	1.011	1.144
30	1990	1.522	4.492	0.971	1.302	1.047	0.992	1.062	1.016	1.162
31	1991	1.479	4.281	0.940	1.305	1.054	0.975	1.067	1.016	1.171
32	1992	1.418	4.225	1.008	1.365	1.061	0.992	1.090	1.013	1.174
33	1993	1.358	4.100	0.998	1.344	1.067	1.003	1.079	1.011	1.150
34	1994	1.290	4.273	0.986	1.284	1.074	0.999	1.041	1.011	1.138
35	1995	1.326	4.544	1.053	1.323	1.081	1.000	1.051	1.014	1.149
36	1996	1.362	5.062	1.105	1.374	1.087	0.981	1.066	1.013	1.193
37	1997	1.359	5.086	1.173	1.377	1.094	0.983	1.061	1.014	1.190
38	1998	1.372	5.416	1.236	1.391	1.101	1.004	1.062	1.014	1.168
39	1999	1.420	5.324	1.321	1.443	1.108	0.997	1.087	1.014	1.186
40	2000	1.419	5.727	1.371	1.454	1.115	0.994	1.083	1.021	1.186
41	2001	1.422	5.755	1.408	1.464	1.116	1.005	1.087	1.015	1.183
42	2002	1.376	5.885	1.394	1.426	1.116	1.017	1.081	1.015	1.146
43	2003	1.347	5.987	1.404	1.437	1.117	0.968	1.105	1.013	1.187

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	1.431	6.663	1.536	1.529	1.118	0.993	1.106	1.017	1.224
45	2005	1.382	6.231	1.522	1.469	1.118	0.991	1.092	1.014	1.198
46	2006	1.362	6.265	1.519	1.478	1.119	0.987	1.108	1.019	1.185
47	2007	1.395	6.317	1.584	1.503	1.120	1.012	1.122	1.012	1.168
48	2008	1.442	8.183	1.673	1.582	1.120	0.990	1.123	1.015	1.252
49	2009	1.458	8.809	1.724	1.574	1.121	0.995	1.116	1.017	1.243
50	2010	1.442	8.939	1.719	1.570	1.122	1.004	1.126	1.017	1.217
51	2011	1.441	8.786	1.750	1.606	1.123	0.983	1.148	1.019	1.245
52	2012	1.443	9.161	1.775	1.572	1.123	0.992	1.125	1.017	1.234
53	2013	1.451	9.870	1.820	1.544	1.124	0.995	1.111	1.017	1.222
54	2014	1.521	10.385	1.935	1.606	1.125	0.986	1.110	1.022	1.277
55	2015	1.490	10.320	1.920	1.586	1.126	0.979	1.119	1.020	1.261
56	2016	1.488	10.631	1.934	1.611	1.126	0.988	1.141	1.021	1.243
57	2017	1.477	10.720	1.948	1.624	1.127	1.003	1.148	1.015	1.232
58	2018	1.421	10.434	1.895	1.714	1.128	0.964	1.168	1.021	1.321
59	2019	1.450	10.911	1.931	1.720	1.129	0.981	1.152	1.021	1.320
60	2020	1.464	11.108	1.968	1.756	1.130	0.978	1.165	1.023	1.333
61	2021	1.447	10.702	1.896	1.838	1.151	0.998	1.194	1.020	1.313

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

India

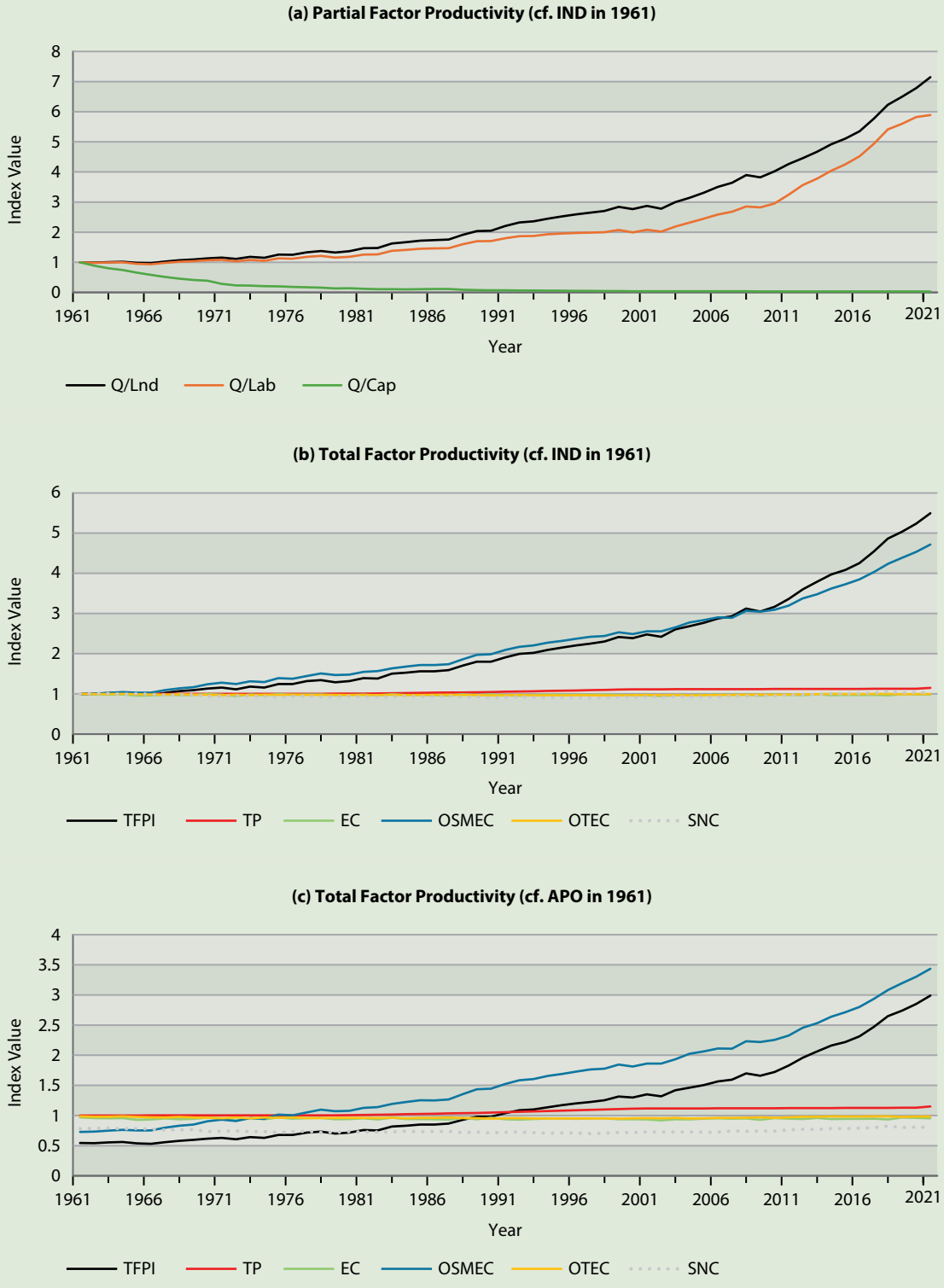
India is among the top three global producers of several crops. In 2021, its agriculture sector employed 38.6% (59.2%) of the male (female) labor force and contributed 17.4% to the country's GDP (FAO, 2025a, 2025b). The agriculture sector in India is large and diverse, with an arable land area second only to the US. Figure 14 reports the estimated changes in agricultural productivity in India from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 18. Figure 14(a) indicates that land and labor productivity increased steadily over the sample period; in 2021, the output per unit of land (labor) was 7.147 (5.888) times higher than that in 1961. However, capital productivity fell dramatically over the sample period; in 2021, the output per unit of capital was 3% of that in 1961. Figure 14(b) indicates that the TFP in Indian agriculture was 5.496 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.985 \times 1.151 \times 4.718 \times 0.999 \times 1.028 \\ &= 5.496. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a small impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) increased TFP by a factor of 4.718, (iv) technical efficiency (OTEC) had a negligible effect on TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 2.8% increase in measured TFP.

FIGURE 14

PRODUCTIVITY CHANGE IN INDIA



Source: Authors' illustration.

TABLE 18

PRODUCTIVITY CHANGE IN INDIA

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	0.986	0.984	0.889	0.998	1.000	0.986	1.006	0.995	1.010
3	1963	1.007	0.993	0.800	1.020	1.001	0.983	1.027	0.996	1.014
4	1964	1.023	0.999	0.744	1.028	1.001	0.988	1.045	1.001	0.994
5	1965	0.980	0.949	0.657	0.987	1.001	0.958	1.032	0.992	1.005
6	1966	0.975	0.936	0.586	0.976	1.002	0.965	1.032	0.986	0.992
7	1967	1.026	0.979	0.513	1.026	1.002	0.979	1.095	0.981	0.973
8	1968	1.067	1.016	0.459	1.069	1.002	0.967	1.140	0.992	0.976
9	1969	1.094	1.036	0.411	1.096	1.002	0.973	1.168	0.982	0.980
10	1970	1.132	1.067	0.387	1.135	1.003	0.995	1.243	0.977	0.937
11	1971	1.159	1.081	0.283	1.156	1.003	0.985	1.278	0.969	0.945
12	1972	1.113	1.031	0.232	1.112	1.003	0.948	1.249	0.981	0.955
13	1973	1.179	1.085	0.230	1.181	1.003	0.989	1.313	0.968	0.937
14	1974	1.153	1.051	0.206	1.156	1.004	0.967	1.295	0.981	0.938
15	1975	1.254	1.132	0.202	1.248	1.004	0.999	1.394	0.975	0.916
16	1976	1.250	1.118	0.185	1.244	1.004	0.977	1.377	0.981	0.939
17	1977	1.334	1.182	0.170	1.319	1.004	0.988	1.446	0.972	0.946
18	1978	1.373	1.210	0.156	1.345	1.004	0.989	1.509	0.972	0.923
19	1979	1.326	1.158	0.134	1.288	1.005	0.968	1.472	0.976	0.922
20	1980	1.372	1.184	0.141	1.320	1.005	0.972	1.482	0.974	0.937
21	1981	1.466	1.260	0.120	1.394	1.009	0.985	1.548	0.975	0.931
22	1982	1.473	1.260	0.110	1.384	1.013	0.964	1.566	0.973	0.930
23	1983	1.623	1.380	0.111	1.506	1.017	0.994	1.636	0.977	0.931
24	1984	1.668	1.415	0.104	1.529	1.022	0.971	1.682	0.968	0.947
25	1985	1.720	1.451	0.110	1.562	1.026	0.971	1.721	0.975	0.934
26	1986	1.739	1.462	0.114	1.564	1.030	0.968	1.718	0.976	0.936
27	1987	1.754	1.471	0.117	1.595	1.034	0.959	1.740	0.980	0.943
28	1988	1.915	1.598	0.092	1.706	1.039	0.992	1.858	0.971	0.918
29	1989	2.036	1.697	0.076	1.803	1.043	0.969	1.972	0.972	0.931
30	1990	2.049	1.703	0.072	1.800	1.047	0.993	1.986	0.961	0.907
31	1991	2.203	1.802	0.070	1.911	1.054	0.967	2.094	0.968	0.924
32	1992	2.323	1.870	0.066	1.999	1.061	0.960	2.175	0.972	0.929
33	1993	2.360	1.871	0.062	2.023	1.067	0.971	2.205	0.965	0.918
34	1994	2.448	1.932	0.059	2.092	1.074	0.982	2.273	0.967	0.903
35	1995	2.521	1.956	0.059	2.155	1.081	0.980	2.320	0.964	0.909
36	1996	2.591	1.974	0.051	2.208	1.087	0.976	2.372	0.966	0.909
37	1997	2.647	1.987	0.051	2.249	1.094	0.980	2.422	0.966	0.896
38	1998	2.706	2.000	0.048	2.305	1.101	0.983	2.443	0.964	0.904
39	1999	2.840	2.075	0.048	2.417	1.108	0.969	2.536	0.962	0.922
40	2000	2.768	1.992	0.043	2.386	1.115	0.967	2.489	0.969	0.917
41	2001	2.875	2.079	0.042	2.482	1.116	0.964	2.559	0.972	0.928
42	2002	2.777	2.015	0.039	2.422	1.116	0.948	2.556	0.969	0.925
43	2003	2.996	2.185	0.040	2.607	1.117	0.968	2.654	0.973	0.934

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	3.144	2.314	0.040	2.685	1.118	0.964	2.778	0.965	0.929
45	2005	3.309	2.451	0.039	2.768	1.118	0.976	2.835	0.967	0.925
46	2006	3.504	2.586	0.038	2.877	1.119	0.983	2.902	0.974	0.925
47	2007	3.638	2.678	0.037	2.932	1.120	0.976	2.895	0.975	0.951
48	2008	3.897	2.857	0.037	3.122	1.120	0.980	3.067	0.980	0.946
49	2009	3.822	2.820	0.035	3.052	1.121	0.957	3.046	0.984	0.949
50	2010	4.018	2.952	0.034	3.169	1.122	0.987	3.096	0.976	0.947
51	2011	4.263	3.247	0.034	3.363	1.123	0.978	3.195	0.983	0.975
52	2012	4.458	3.567	0.034	3.604	1.123	0.970	3.376	0.993	0.987
53	2013	4.668	3.779	0.033	3.791	1.124	0.992	3.479	0.994	0.983
54	2014	4.918	4.038	0.033	3.974	1.125	0.969	3.624	1.000	1.005
55	2015	5.106	4.252	0.032	4.083	1.126	0.976	3.728	0.996	1.001
56	2016	5.348	4.519	0.031	4.256	1.126	0.973	3.849	0.997	1.013
57	2017	5.767	4.935	0.031	4.543	1.127	0.978	4.030	1.001	1.022
58	2018	6.231	5.414	0.032	4.867	1.128	0.963	4.234	1.001	1.058
59	2019	6.498	5.600	0.031	5.037	1.129	0.998	4.386	0.992	1.027
60	2020	6.786	5.825	0.036	5.238	1.130	0.990	4.534	0.998	1.035
61	2021	7.147	5.888	0.030	5.496	1.151	0.985	4.718	0.999	1.028

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Indonesia

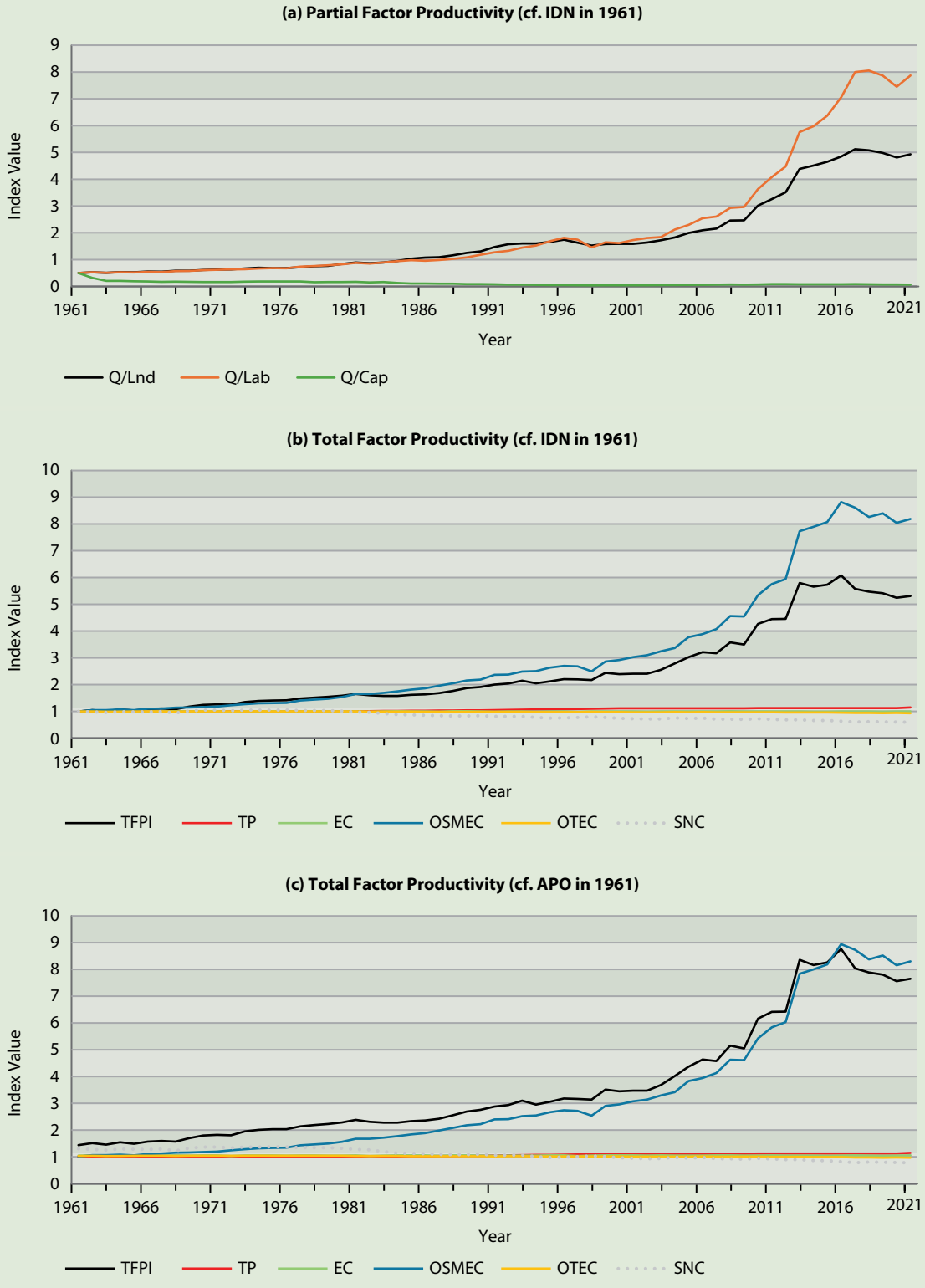
Indonesia is a key global player in the production of tropical products. In 2021, its agriculture sector employed 31% (26%) of the male (female) labor force and contributed 13.3% to the country's GDP (FAO, 2025a, 2025b). Indonesia is the world's largest producer of palm oil and the third largest producer of rice. Other important products include rubber, coffee, and tobacco. Figure 15 reports the estimated changes in agricultural productivity in Indonesia from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 19. Figure 15(a) indicates that land and labor productivity increased steadily over the sample period; in 2021, the output per unit of land (labor) was 9.858 (15.738) times higher than that in 1961. However, capital productivity fell sharply; by 2021, the output per unit of capital had fallen to 13.2% of its level in 1961. Figure 15(b) indicates that the TFP in Indonesian agriculture was 5.313 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 1.007 \times 1.151 \times 8.190 \times 0.934 \times 0.599 \\ &= 5.313. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a negligible impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) increased TFP by a factor of 8.190, (iv) lower technical efficiency (OTEC) led to a 6.6% fall in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 40.1% fall in measured TFP.

FIGURE 15

PRODUCTIVITY CHANGE IN INDONESIA



Source: Authors' illustration.

TABLE 19

PRODUCTIVITY CHANGE IN INDONESIA

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.062	1.059	0.633	1.053	1.000	1.011	1.054	1.002	0.986
3	1963	1.015	1.010	0.417	1.011	1.001	0.997	1.052	0.998	0.965
4	1964	1.074	1.061	0.415	1.075	1.001	1.010	1.073	0.997	0.994
5	1965	1.061	1.046	0.379	1.037	1.001	0.997	1.049	1.002	0.988
6	1966	1.115	1.093	0.373	1.093	1.002	1.007	1.097	1.002	0.986
7	1967	1.102	1.077	0.348	1.109	1.002	1.001	1.107	1.001	0.998
8	1968	1.170	1.148	0.353	1.089	1.002	1.009	1.143	0.998	0.943
9	1969	1.171	1.154	0.338	1.181	1.002	1.004	1.146	1.005	1.019
10	1970	1.221	1.210	0.335	1.249	1.003	1.009	1.169	1.004	1.051
11	1971	1.252	1.240	0.329	1.268	1.003	1.010	1.180	1.007	1.053
12	1972	1.262	1.273	0.333	1.257	1.003	0.988	1.233	1.004	1.024
13	1973	1.339	1.280	0.354	1.357	1.003	1.009	1.271	1.004	1.051
14	1974	1.390	1.333	0.370	1.396	1.004	1.007	1.305	1.007	1.051
15	1975	1.372	1.372	0.364	1.414	1.004	1.011	1.316	1.003	1.055
16	1976	1.367	1.360	0.364	1.415	1.004	1.002	1.325	1.004	1.058
17	1977	1.436	1.473	0.367	1.483	1.004	1.007	1.412	1.003	1.036
18	1978	1.508	1.519	0.310	1.520	1.004	1.010	1.444	1.003	1.035
19	1979	1.531	1.575	0.324	1.548	1.005	1.003	1.476	1.006	1.034
20	1980	1.678	1.655	0.333	1.589	1.005	1.005	1.543	1.004	1.015
21	1981	1.793	1.756	0.337	1.652	1.009	1.008	1.657	1.000	0.981
22	1982	1.729	1.702	0.304	1.605	1.013	0.990	1.653	0.999	0.970
23	1983	1.786	1.792	0.326	1.582	1.017	1.004	1.694	0.994	0.920
24	1984	1.899	1.894	0.254	1.582	1.022	1.011	1.752	0.994	0.879
25	1985	2.073	1.951	0.215	1.620	1.026	1.007	1.814	0.992	0.871
26	1986	2.149	1.908	0.211	1.639	1.030	1.007	1.862	0.991	0.856
27	1987	2.177	1.973	0.199	1.685	1.034	0.998	1.963	0.989	0.841
28	1988	2.318	2.057	0.197	1.772	1.039	1.008	2.053	0.991	0.832
29	1989	2.503	2.172	0.179	1.871	1.043	1.008	2.155	0.990	0.834
30	1990	2.610	2.360	0.173	1.917	1.047	1.001	2.189	0.990	0.844
31	1991	2.936	2.544	0.163	2.001	1.054	0.997	2.370	0.985	0.816
32	1992	3.151	2.661	0.138	2.040	1.061	1.003	2.375	0.986	0.819
33	1993	3.212	2.901	0.128	2.152	1.067	1.001	2.489	0.989	0.819
34	1994	3.210	3.054	0.114	2.049	1.074	0.999	2.511	0.978	0.777
35	1995	3.316	3.368	0.109	2.122	1.081	1.007	2.637	0.982	0.753
36	1996	3.494	3.631	0.107	2.211	1.087	1.006	2.704	0.981	0.762
37	1997	3.263	3.487	0.094	2.198	1.094	0.987	2.684	0.977	0.776
38	1998	3.048	2.916	0.080	2.178	1.101	1.004	2.503	0.985	0.799
39	1999	3.165	3.293	0.088	2.440	1.108	1.008	2.864	0.979	0.779
40	2000	3.173	3.232	0.085	2.391	1.115	1.007	2.923	0.978	0.745
41	2001	3.185	3.463	0.087	2.414	1.116	1.006	3.031	0.974	0.728
42	2002	3.280	3.608	0.091	2.409	1.116	0.999	3.100	0.973	0.716
43	2003	3.438	3.689	0.098	2.557	1.117	1.006	3.249	0.973	0.719

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	3.658	4.246	0.105	2.791	1.118	1.001	3.370	0.976	0.758
45	2005	3.997	4.598	0.115	3.030	1.118	1.004	3.778	0.974	0.734
46	2006	4.193	5.086	0.124	3.215	1.119	1.002	3.892	0.977	0.754
47	2007	4.314	5.208	0.128	3.177	1.120	1.007	4.077	0.971	0.712
48	2008	4.913	5.858	0.146	3.578	1.120	1.009	4.561	0.973	0.714
49	2009	4.937	5.931	0.132	3.502	1.121	1.004	4.552	0.972	0.703
50	2010	6.024	7.270	0.152	4.275	1.122	1.005	5.347	0.972	0.729
51	2011	6.523	8.168	0.169	4.451	1.123	1.007	5.759	0.968	0.706
52	2012	7.021	8.945	0.169	4.457	1.123	1.005	5.950	0.963	0.689
53	2013	8.767	11.513	0.159	5.800	1.124	1.006	7.733	0.964	0.688
54	2014	9.020	11.949	0.153	5.663	1.125	0.999	7.894	0.960	0.664
55	2015	9.294	12.741	0.157	5.735	1.126	0.995	8.077	0.961	0.660
56	2016	9.697	14.109	0.161	6.083	1.126	1.005	8.822	0.957	0.636
57	2017	10.240	15.997	0.169	5.582	1.127	1.007	8.611	0.944	0.605
58	2018	10.160	16.109	0.161	5.475	1.128	1.005	8.260	0.944	0.619
59	2019	9.954	15.734	0.144	5.414	1.129	0.995	8.403	0.937	0.612
60	2020	9.623	14.906	0.141	5.249	1.130	1.005	8.047	0.945	0.608
61	2021	9.858	15.738	0.132	5.313	1.151	1.007	8.190	0.934	0.599

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

I.R. Iran

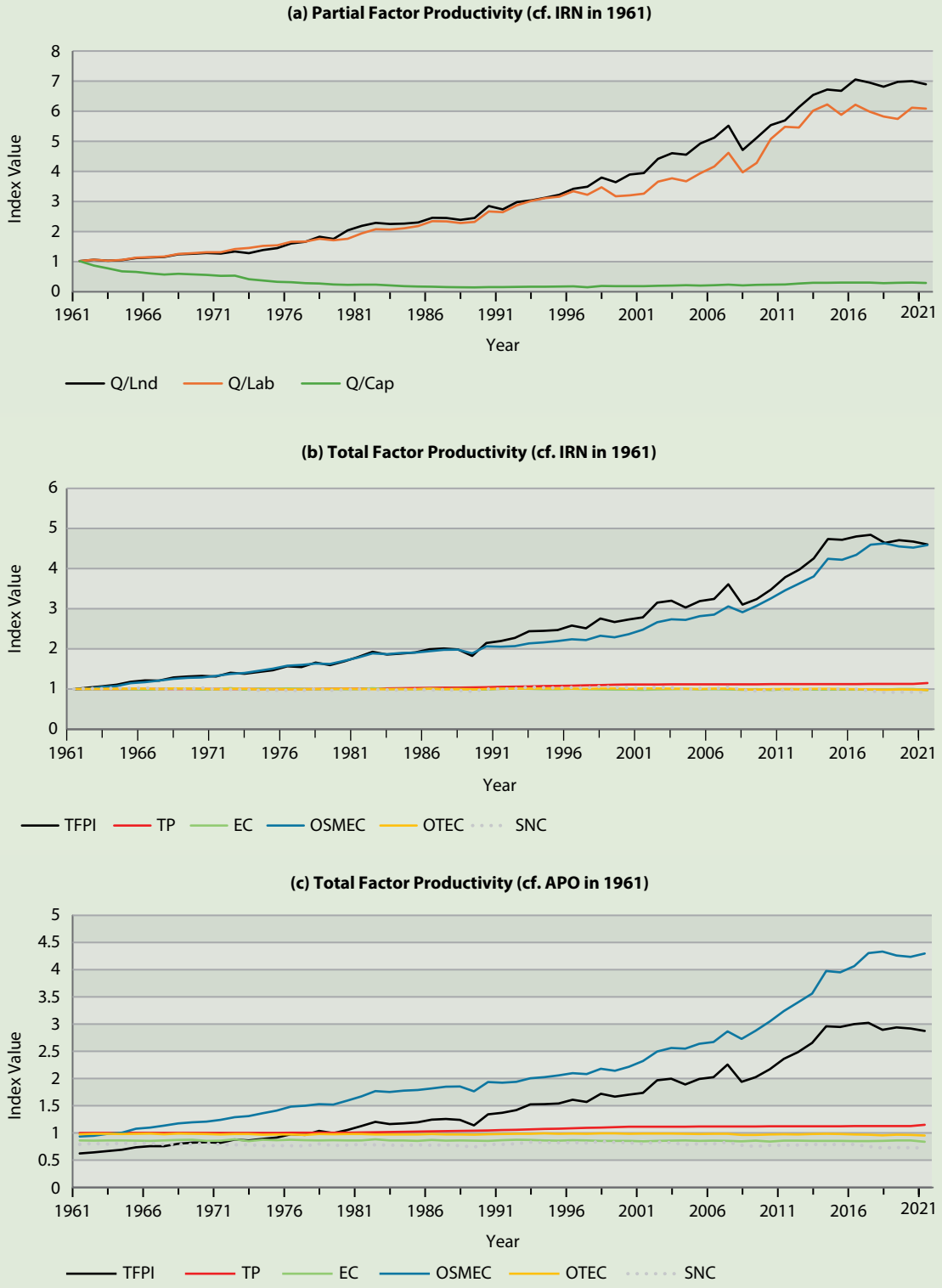
Approximately one third of I.R. Iran's total land area is suitable for farming. In 2021, its agriculture sector employed 15.2% (17.2%) of the male (female) labor force and contributed 12.4% to the country's GDP (FAO, 2025a, 2025b). Figure 16 reports the estimated changes in agricultural productivity in I.R. Iran from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 20. Figure 16(a) indicates an increase in both land and labor productivity over the sample period; in 2021, the output per unit of land (labor) was 6.893 (6.081) times higher than that in 1961. However, capital productivity fell significantly over the sample period; in 2021, the output per unit of capital was 72.7% lower than that in 1961. Figure 16(b) indicates that the TFP in Iranian agriculture was 4.604 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.972 \times 1.151 \times 4.589 \times 0.977 \times 0.917 \\ &= 4.604. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a negative but small impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) increased TFP by a factor of 4.589, (iv) improved technical efficiency (OTEC) led to a small decrease in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 8.3% fall in measured TFP. In the case of I.R. Iran, the increase in scale-mix efficiency can be partly attributed to a shift from crops into livestock (i.e., a more productive output mix).

FIGURE 16

PRODUCTIVITY CHANGE IN I.R. IRAN



Source: Authors' illustration.

TABLE 20

PRODUCTIVITY CHANGE IN I.R. IRAN

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.043	1.044	0.851	1.034	1.000	0.995	1.013	1.008	1.016
3	1963	1.012	1.016	0.756	1.071	1.001	1.002	1.054	1.009	1.006
4	1964	1.029	1.036	0.660	1.111	1.001	1.000	1.073	1.007	1.027
5	1965	1.101	1.111	0.639	1.182	1.001	0.997	1.150	1.012	1.017
6	1966	1.122	1.132	0.592	1.215	1.002	0.989	1.175	1.013	1.030
7	1967	1.139	1.152	0.553	1.213	1.002	0.999	1.211	1.003	0.997
8	1968	1.224	1.239	0.577	1.288	1.002	1.010	1.258	1.014	0.997
9	1969	1.246	1.265	0.557	1.316	1.002	1.014	1.278	1.012	1.001
10	1970	1.267	1.293	0.540	1.331	1.003	0.990	1.290	1.007	1.033
11	1971	1.251	1.296	0.506	1.313	1.003	0.995	1.327	0.999	0.992
12	1972	1.320	1.401	0.515	1.407	1.003	1.023	1.378	1.006	0.989
13	1973	1.262	1.440	0.394	1.381	1.003	0.985	1.400	1.006	0.992
14	1974	1.372	1.505	0.349	1.426	1.004	1.014	1.458	0.994	0.968
15	1975	1.434	1.525	0.308	1.468	1.004	1.004	1.508	0.996	0.970
16	1976	1.589	1.643	0.294	1.567	1.004	1.017	1.585	0.999	0.969
17	1977	1.644	1.650	0.265	1.548	1.004	1.007	1.604	0.991	0.964
18	1978	1.810	1.746	0.250	1.661	1.004	0.999	1.636	1.005	1.008
19	1979	1.738	1.694	0.220	1.595	1.005	1.004	1.628	1.002	0.970
20	1980	2.026	1.741	0.208	1.691	1.005	0.999	1.703	1.007	0.982
21	1981	2.174	1.922	0.216	1.804	1.009	0.999	1.788	1.004	0.998
22	1982	2.275	2.061	0.216	1.931	1.013	1.022	1.890	0.999	0.987
23	1983	2.235	2.048	0.187	1.862	1.017	0.999	1.872	0.998	0.981
24	1984	2.251	2.095	0.166	1.885	1.022	1.002	1.901	0.997	0.971
25	1985	2.287	2.167	0.152	1.916	1.026	0.991	1.910	0.996	0.990
26	1986	2.443	2.333	0.147	1.993	1.030	1.011	1.944	1.005	0.979
27	1987	2.438	2.326	0.136	2.014	1.034	0.996	1.978	0.998	0.990
28	1988	2.372	2.269	0.126	1.989	1.039	1.001	1.982	0.999	0.966
29	1989	2.437	2.304	0.123	1.827	1.043	0.996	1.888	0.992	0.939
30	1990	2.833	2.652	0.135	2.149	1.047	0.990	2.066	1.003	1.000
31	1991	2.721	2.628	0.133	2.197	1.054	1.006	2.057	1.007	1.000
32	1992	2.966	2.857	0.140	2.276	1.061	1.013	2.072	1.010	1.012
33	1993	3.022	3.005	0.145	2.443	1.067	1.008	2.141	1.010	1.050
34	1994	3.113	3.094	0.148	2.453	1.074	0.999	2.165	1.017	1.038
35	1995	3.207	3.148	0.151	2.471	1.081	0.995	2.198	1.011	1.034
36	1996	3.409	3.330	0.159	2.583	1.087	1.006	2.240	1.014	1.039
37	1997	3.479	3.211	0.127	2.516	1.094	0.999	2.223	1.008	1.027
38	1998	3.784	3.458	0.172	2.758	1.101	0.993	2.327	1.016	1.066
39	1999	3.626	3.160	0.162	2.671	1.108	0.990	2.288	1.018	1.046
40	2000	3.883	3.188	0.165	2.732	1.115	0.989	2.370	1.009	1.036
41	2001	3.932	3.248	0.164	2.785	1.116	0.982	2.479	1.016	1.010
42	2002	4.409	3.644	0.177	3.154	1.116	0.991	2.667	1.015	1.053
43	2003	4.592	3.762	0.187	3.202	1.117	0.997	2.739	1.012	1.037

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	4.546	3.658	0.196	3.030	1.118	1.000	2.725	1.008	0.987
45	2005	4.920	3.924	0.184	3.191	1.118	0.993	2.819	1.004	1.015
46	2006	5.111	4.155	0.195	3.244	1.119	0.996	2.855	1.010	1.009
47	2007	5.513	4.608	0.215	3.613	1.120	0.993	3.062	1.012	1.049
48	2008	4.698	3.959	0.190	3.106	1.120	0.981	2.914	0.990	0.979
49	2009	5.104	4.272	0.207	3.241	1.121	0.997	3.075	0.990	0.953
50	2010	5.532	5.072	0.212	3.481	1.122	0.977	3.260	0.997	0.978
51	2011	5.689	5.476	0.218	3.786	1.123	0.996	3.463	1.000	0.978
52	2012	6.127	5.449	0.252	3.980	1.123	0.995	3.632	0.999	0.981
53	2013	6.534	6.011	0.278	4.255	1.124	0.989	3.807	1.005	1.000
54	2014	6.716	6.220	0.277	4.740	1.125	0.989	4.246	1.009	0.995
55	2015	6.670	5.873	0.285	4.719	1.126	0.989	4.221	1.004	1.000
56	2016	7.052	6.208	0.283	4.803	1.126	0.985	4.342	0.998	0.998
57	2017	6.948	5.982	0.280	4.843	1.127	0.987	4.599	0.994	0.952
58	2018	6.811	5.817	0.265	4.639	1.128	0.989	4.629	0.980	0.916
59	2019	6.970	5.738	0.278	4.711	1.129	1.000	4.552	0.991	0.925
60	2020	6.995	6.110	0.283	4.674	1.130	1.002	4.524	0.989	0.923
61	2021	6.893	6.081	0.273	4.604	1.151	0.972	4.589	0.977	0.917

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Japan

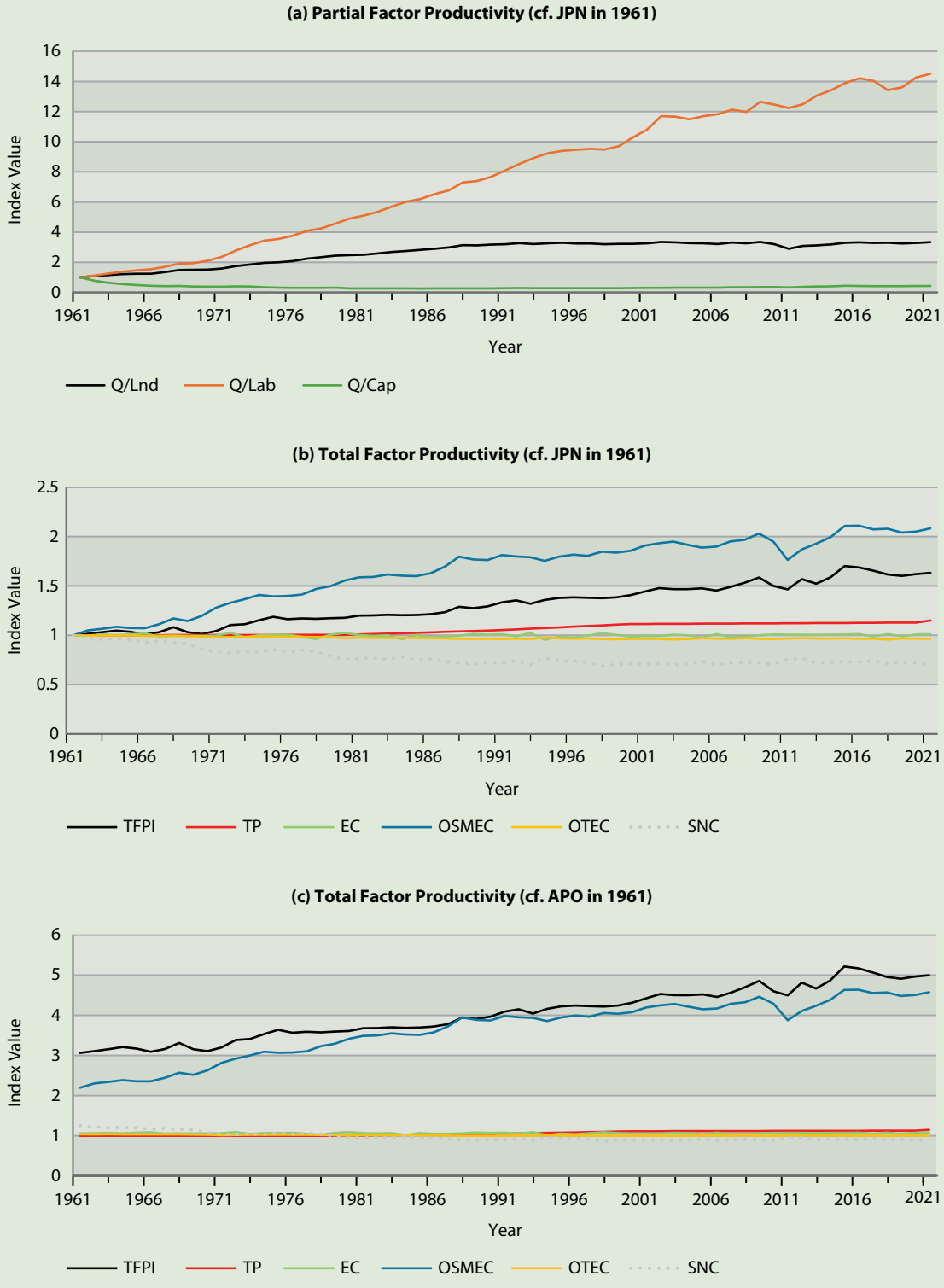
Japanese agriculture is characterized by a shortage of farmland. Farmland constitutes less than 15% of the total land area in Japan and is intensively cultivated. In 2021, its agriculture sector employed 3.5% (2.6%) of the male (female) labor force and contributed 1.0% to the country's GDP (FAO, 2025a, 2025b). Figure 17 reports the estimated changes in agricultural productivity in Japan from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 21. Figure 17(a) indicates that labor productivity increased significantly; in 2021, the output per unit of labor was 14.505 higher than that in 1961. However, capital productivity fell; in 2021, the output per unit of capital was 43.2% of that in 1961. Land productivity increased and, in 2021, it was 3.337 times its 1961 level. Figure 17(b) indicates that the TFP in Japanese agriculture was 63.2% higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 1.010 \times 1.151 \times 2.084 \times 0.965 \times 0.698 \\ &= 1.632. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a small impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) an increase in scale-mix efficiency (OSMEC) led to a 108.4% increase in TFP, (iv) lower technical efficiency (OTEC) led to a 3.5% fall in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 30.2% fall in measured TFP.

FIGURE 17

PRODUCTIVITY CHANGE IN JAPAN



Source: Authors' illustration.

TABLE 21

PRODUCTIVITY CHANGE IN JAPAN

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.086	1.120	0.784	1.015	1.000	0.997	1.049	0.996	0.975
3	1963	1.149	1.252	0.642	1.031	1.001	1.009	1.066	0.999	0.958
4	1964	1.211	1.378	0.559	1.047	1.001	1.000	1.087	0.998	0.964
5	1965	1.241	1.460	0.489	1.035	1.001	1.011	1.074	0.998	0.953
6	1966	1.241	1.542	0.440	1.009	1.002	1.019	1.072	0.995	0.927
7	1967	1.352	1.703	0.419	1.031	1.002	0.988	1.112	0.995	0.941
8	1968	1.488	1.912	0.425	1.082	1.002	0.995	1.171	0.996	0.930
9	1969	1.508	1.945	0.388	1.031	1.002	0.994	1.146	0.990	0.912
10	1970	1.515	2.098	0.381	1.013	1.003	0.995	1.197	0.988	0.859
11	1971	1.592	2.369	0.385	1.044	1.003	0.998	1.282	0.978	0.832
12	1972	1.754	2.787	0.405	1.104	1.003	1.026	1.331	0.982	0.820
13	1973	1.858	3.137	0.397	1.113	1.003	0.979	1.367	0.985	0.841
14	1974	1.966	3.435	0.346	1.153	1.004	1.001	1.408	0.988	0.825
15	1975	2.003	3.544	0.317	1.187	1.004	1.003	1.396	0.985	0.857
16	1976	2.081	3.758	0.307	1.164	1.004	1.008	1.400	0.988	0.832
17	1977	2.238	4.082	0.307	1.172	1.004	0.985	1.413	0.985	0.851
18	1978	2.334	4.244	0.303	1.167	1.004	0.962	1.471	0.982	0.836
19	1979	2.443	4.565	0.312	1.173	1.005	1.006	1.499	0.980	0.790
20	1980	2.479	4.901	0.268	1.177	1.005	1.026	1.555	0.969	0.757
21	1981	2.500	5.097	0.271	1.200	1.009	1.003	1.589	0.976	0.765
22	1982	2.590	5.346	0.268	1.203	1.013	0.995	1.592	0.974	0.769
23	1983	2.689	5.699	0.271	1.208	1.017	1.001	1.617	0.972	0.755
24	1984	2.751	6.024	0.270	1.203	1.022	0.959	1.604	0.976	0.785
25	1985	2.821	6.199	0.257	1.207	1.026	1.003	1.600	0.973	0.753
26	1986	2.901	6.525	0.265	1.215	1.030	0.983	1.629	0.973	0.757
27	1987	2.988	6.774	0.266	1.234	1.034	0.987	1.696	0.969	0.735
28	1988	3.135	7.294	0.271	1.289	1.039	0.997	1.797	0.965	0.718
29	1989	3.127	7.394	0.264	1.276	1.043	1.015	1.770	0.961	0.708
30	1990	3.180	7.666	0.263	1.294	1.047	1.007	1.762	0.963	0.723
31	1991	3.201	8.089	0.283	1.335	1.054	1.012	1.814	0.963	0.717
32	1992	3.272	8.525	0.289	1.354	1.061	0.989	1.799	0.966	0.743
33	1993	3.212	8.911	0.281	1.319	1.067	1.026	1.792	0.961	0.700
34	1994	3.264	9.224	0.286	1.358	1.074	0.955	1.756	0.978	0.772
35	1995	3.299	9.394	0.281	1.379	1.081	0.987	1.797	0.970	0.742
36	1996	3.250	9.460	0.279	1.384	1.087	0.977	1.818	0.966	0.742
37	1997	3.246	9.523	0.280	1.381	1.094	0.996	1.806	0.968	0.724
38	1998	3.194	9.478	0.277	1.377	1.101	1.020	1.848	0.963	0.688
39	1999	3.220	9.705	0.279	1.385	1.108	1.005	1.839	0.961	0.704
40	2000	3.219	10.274	0.292	1.408	1.115	0.989	1.857	0.965	0.712
41	2001	3.259	10.805	0.299	1.443	1.116	0.993	1.909	0.965	0.707
42	2002	3.349	11.696	0.311	1.478	1.116	0.992	1.933	0.965	0.715
43	2003	3.329	11.658	0.313	1.468	1.117	1.007	1.951	0.958	0.698

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	3.280	11.481	0.312	1.469	1.118	1.001	1.918	0.962	0.712
45	2005	3.256	11.697	0.314	1.476	1.118	0.976	1.889	0.970	0.738
46	2006	3.216	11.828	0.319	1.454	1.119	1.013	1.898	0.966	0.700
47	2007	3.315	12.124	0.338	1.490	1.120	0.982	1.952	0.965	0.719
48	2008	3.267	11.968	0.342	1.534	1.120	0.985	1.969	0.972	0.726
49	2009	3.351	12.642	0.361	1.586	1.121	1.000	2.031	0.965	0.721
50	2010	3.194	12.456	0.353	1.501	1.122	1.010	1.951	0.961	0.706
51	2011	2.905	12.240	0.333	1.467	1.123	1.007	1.765	0.968	0.760
52	2012	3.093	12.487	0.368	1.571	1.123	1.007	1.870	0.973	0.763
53	2013	3.128	13.076	0.387	1.523	1.124	1.004	1.929	0.969	0.722
54	2014	3.184	13.419	0.408	1.589	1.125	1.007	1.995	0.967	0.727
55	2015	3.299	13.898	0.439	1.702	1.126	1.009	2.109	0.970	0.733
56	2016	3.321	14.212	0.434	1.688	1.126	1.013	2.111	0.965	0.726
57	2017	3.284	14.028	0.422	1.654	1.127	0.987	2.074	0.966	0.742
58	2018	3.294	13.423	0.415	1.617	1.128	1.012	2.079	0.957	0.711
59	2019	3.254	13.606	0.415	1.603	1.129	0.989	2.041	0.969	0.726
60	2020	3.281	14.264	0.426	1.621	1.130	1.008	2.051	0.966	0.718
61	2021	3.337	14.505	0.432	1.632	1.151	1.010	2.084	0.965	0.698

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

The ROK

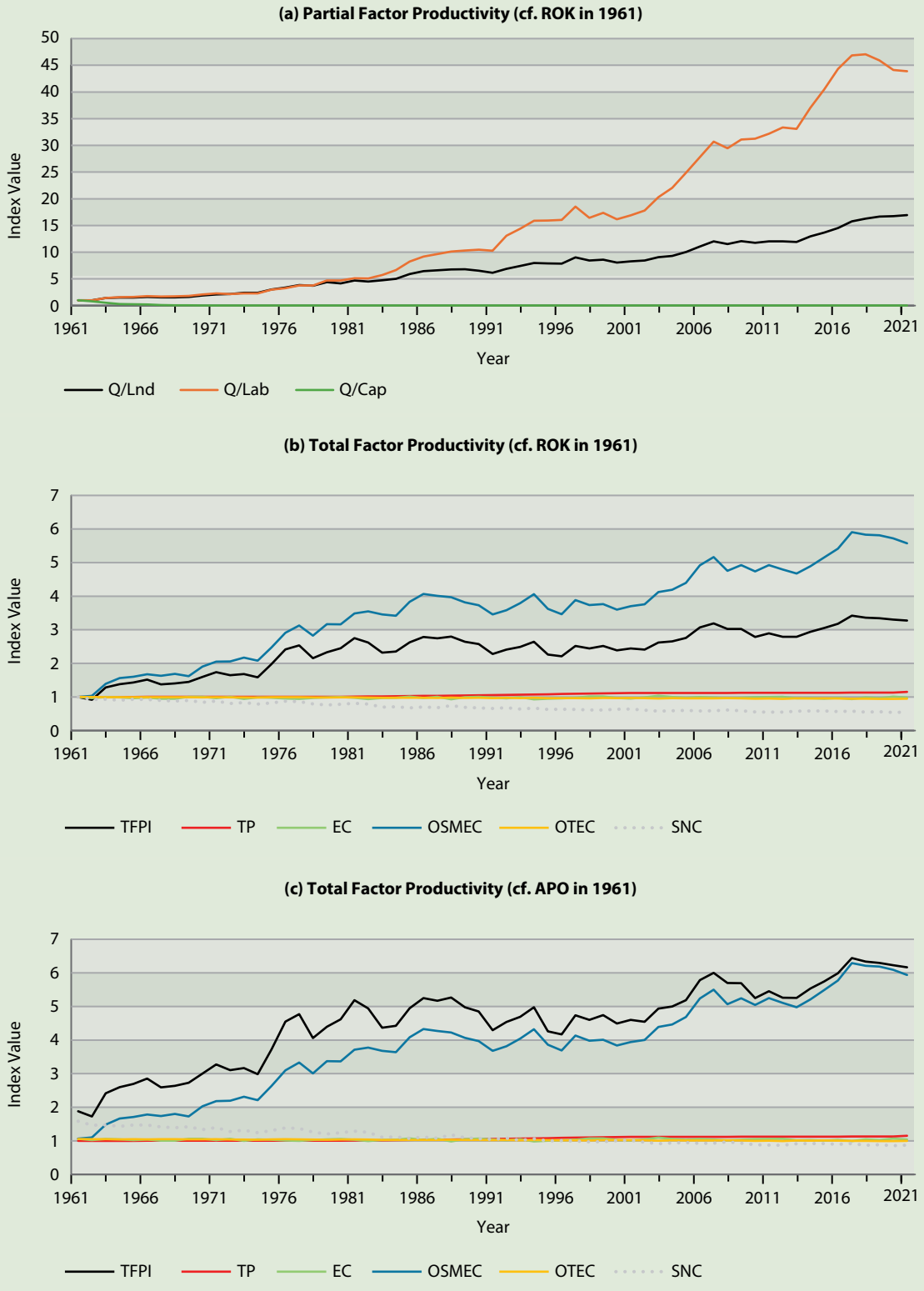
In 2021, the agriculture sector in the ROK employed 5.8% (4.7%) of the male (female) labor force and contributed 1.7% to the country's GDP (FAO, 2025a, 2025b). The most important agricultural industry is rice, which accounts for more than 90% of the total grain production and almost half of the farm income. Figure 18 reports the estimated changes in agricultural productivity in the ROK from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 22. Figure 18(a) indicates that land and labor productivity increased steadily over the sample period; in 2021, the output per unit of land (labor) was 16.943 (43.879) times higher than that in 1961. However, capital productivity fell significantly over the sample period; in 2021, the output per unit of capital was 0.002. Figure 18(b) indicates that the TFP in Korean agriculture was 3.275 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.979 \times 1.151 \times 5.575 \times 0.946 \times 0.551 \\ &= 3.275. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) contributed to a 2.1% fall in TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) increased TFP by a factor of 5.575, (iv) lower technical efficiency (OTEC) led to a 5.4% fall in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a sharp 44.9% fall in measured TFP.

FIGURE 18

PRODUCTIVITY CHANGE IN THE ROK



Source: Authors' illustration.

TABLE 22

PRODUCTIVITY CHANGE IN THE ROK

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	0.986	0.979	0.805	0.916	1.000	0.965	1.032	0.996	0.923
3	1963	1.409	1.417	0.506	1.283	1.001	0.998	1.392	0.994	0.928
4	1964	1.497	1.568	0.284	1.379	1.001	0.985	1.560	0.992	0.903
5	1965	1.495	1.624	0.231	1.431	1.001	0.965	1.604	0.995	0.928
6	1966	1.620	1.770	0.202	1.514	1.002	0.981	1.675	0.993	0.927
7	1967	1.522	1.700	0.085	1.377	1.002	0.948	1.629	0.995	0.894
8	1968	1.535	1.715	0.058	1.400	1.002	0.947	1.690	0.995	0.878
9	1969	1.621	1.806	0.042	1.449	1.002	1.005	1.620	0.991	0.896
10	1970	1.887	2.069	0.035	1.595	1.003	1.003	1.905	0.990	0.842
11	1971	2.078	2.284	0.025	1.739	1.003	0.966	2.051	0.993	0.881
12	1972	2.160	2.144	0.018	1.648	1.003	1.004	2.058	0.987	0.806
13	1973	2.379	2.268	0.013	1.681	1.003	0.942	2.171	0.986	0.831
14	1974	2.408	2.294	0.008	1.585	1.004	0.986	2.077	0.981	0.786
15	1975	3.014	2.972	0.008	1.975	1.004	0.978	2.470	0.991	0.823
16	1976	3.380	3.238	0.007	2.416	1.004	0.954	2.910	0.993	0.873
17	1977	3.823	3.757	0.006	2.534	1.004	0.942	3.129	0.992	0.863
18	1978	3.724	3.777	0.004	2.154	1.004	0.970	2.824	0.985	0.795
19	1979	4.374	4.684	0.004	2.333	1.005	0.986	3.167	0.981	0.758
20	1980	4.153	4.676	0.003	2.451	1.005	0.999	3.158	0.985	0.785
21	1981	4.681	5.110	0.003	2.753	1.009	0.975	3.486	0.988	0.812
22	1982	4.490	5.098	0.002	2.623	1.013	0.938	3.547	0.984	0.791
23	1983	4.727	5.722	0.002	2.318	1.017	0.970	3.456	0.973	0.698
24	1984	4.994	6.639	0.002	2.351	1.022	0.977	3.419	0.974	0.707
25	1985	5.917	8.241	0.002	2.627	1.026	1.011	3.834	0.976	0.677
26	1986	6.450	9.180	0.002	2.788	1.030	0.972	4.065	0.977	0.701
27	1987	6.613	9.656	0.002	2.745	1.034	1.002	4.010	0.973	0.679
28	1988	6.755	10.127	0.002	2.796	1.039	0.928	3.967	0.981	0.745
29	1989	6.810	10.307	0.002	2.643	1.043	0.991	3.814	0.972	0.690
30	1990	6.544	10.448	0.001	2.575	1.047	1.005	3.728	0.974	0.674
31	1991	6.123	10.290	0.001	2.279	1.054	0.983	3.455	0.966	0.659
32	1992	6.867	13.086	0.001	2.410	1.061	0.959	3.580	0.973	0.680
33	1993	7.426	14.425	0.001	2.491	1.067	0.993	3.794	0.966	0.642
34	1994	7.955	15.878	0.001	2.642	1.074	0.928	4.060	0.975	0.670
35	1995	7.892	15.910	0.001	2.262	1.081	0.948	3.623	0.966	0.631
36	1996	7.856	16.053	0.001	2.212	1.087	0.961	3.463	0.963	0.635
37	1997	9.024	18.554	0.001	2.515	1.094	0.977	3.883	0.965	0.628
38	1998	8.436	16.435	0.001	2.444	1.101	1.014	3.736	0.959	0.610
39	1999	8.613	17.378	0.001	2.519	1.108	1.014	3.763	0.970	0.614
40	2000	8.066	16.166	0.001	2.387	1.115	0.973	3.601	0.966	0.633
41	2001	8.275	16.916	0.001	2.443	1.116	0.955	3.701	0.968	0.640
42	2002	8.433	17.790	0.001	2.412	1.116	0.987	3.756	0.962	0.606
43	2003	9.051	20.288	0.001	2.621	1.117	1.037	4.124	0.954	0.575

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	9.283	22.068	0.001	2.653	1.118	0.996	4.192	0.964	0.590
45	2005	10.036	24.893	0.001	2.754	1.118	0.976	4.398	0.959	0.598
46	2006	11.053	27.765	0.001	3.072	1.119	0.998	4.917	0.958	0.584
47	2007	12.022	30.708	0.001	3.187	1.120	0.981	5.162	0.959	0.586
48	2008	11.512	29.459	0.001	3.025	1.120	0.962	4.756	0.963	0.613
49	2009	12.079	31.092	0.001	3.022	1.121	0.974	4.923	0.960	0.586
50	2010	11.748	31.236	0.001	2.786	1.122	0.994	4.737	0.948	0.557
51	2011	12.040	32.199	0.001	2.895	1.123	0.996	4.926	0.955	0.550
52	2012	12.030	33.352	0.001	2.793	1.123	1.005	4.796	0.943	0.547
53	2013	11.899	33.072	0.001	2.789	1.124	0.961	4.673	0.956	0.578
54	2014	12.953	37.051	0.001	2.940	1.125	0.966	4.892	0.952	0.581
55	2015	13.683	40.475	0.001	3.051	1.126	0.947	5.155	0.956	0.581
56	2016	14.532	44.332	0.002	3.180	1.126	0.972	5.417	0.951	0.564
57	2017	15.765	46.866	0.002	3.420	1.127	0.936	5.906	0.948	0.579
58	2018	16.288	47.062	0.002	3.363	1.128	0.987	5.830	0.949	0.546
59	2019	16.666	45.915	0.002	3.344	1.129	0.967	5.812	0.944	0.559
60	2020	16.727	44.121	0.002	3.306	1.130	1.007	5.720	0.942	0.539
61	2021	16.943	43.879	0.002	3.275	1.151	0.979	5.575	0.946	0.551

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Lao PDR

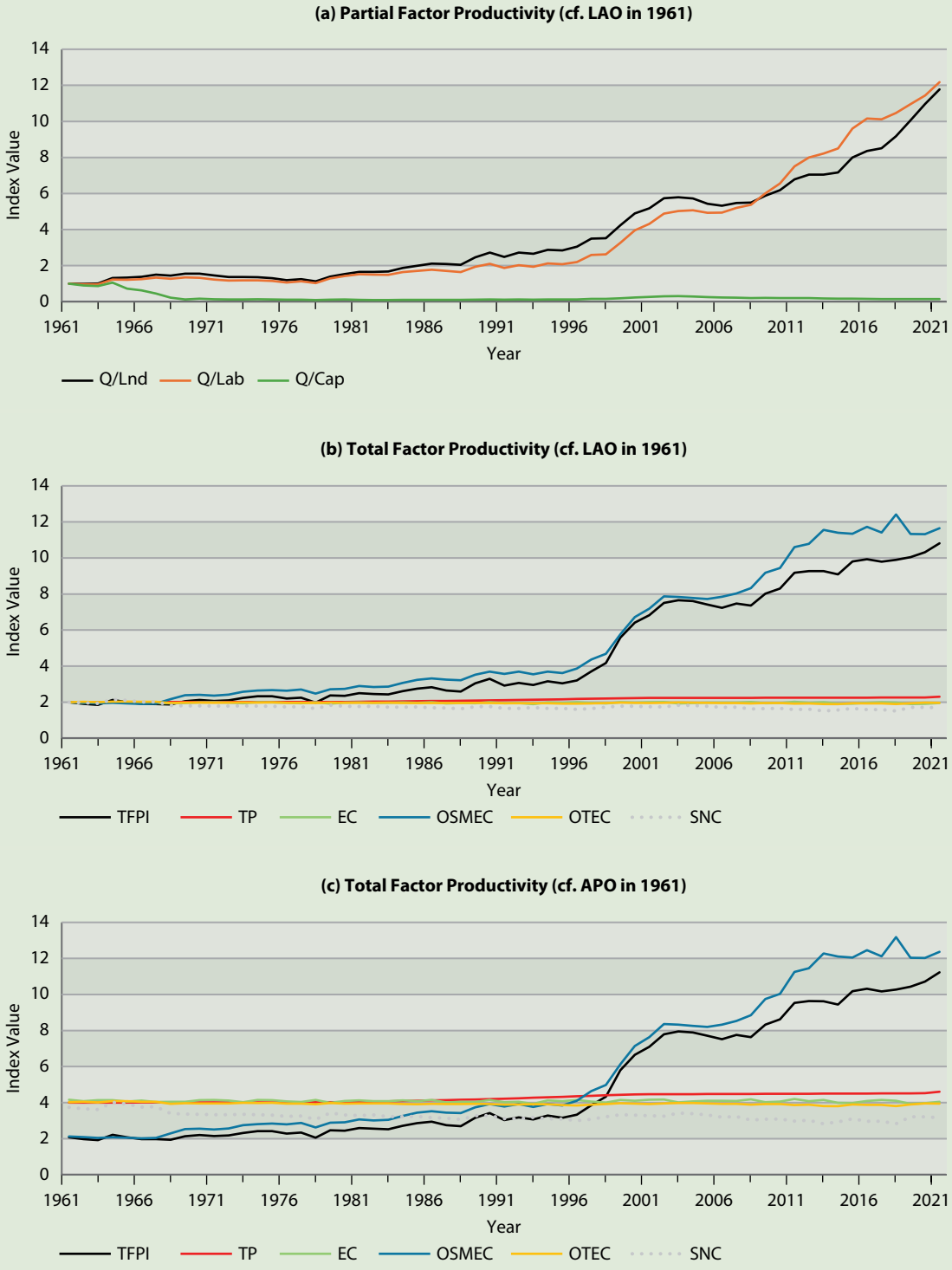
In 2022, the agriculture sector in Lao PDR employed 69.5% (69.6%) of the male (female) labor force and contributed 17.8% to the country's GDP (FAO, 2025a, 2025b). The main agricultural products are rice, coffee, and opium. Slash-and-burn cultivation techniques appear to be causing serious erosion and deforestation problems. Figure 19 reports the estimated changes in agricultural productivity in Lao PDR from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 23. Figure 19(a) indicates that both land and labor productivity increased over the sample period; in 2021, the output per unit of land (labor) was 11.776 (12.175) times higher than that in 1961. However, capital productivity fell sharply; in 2021, the output per unit of capital was 14.7% of that in 1961. Figure 19(b) indicates that the agricultural TFP in Lao PDR was 5.406 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.973 \times 1.151 \times 5.823 \times 0.981 \times 0.845 \\ &= 5.406. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) led to a 2.7% fall in TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) increased TFP by a factor of 5.823, (iv) changes in technical efficiency (OTEC) had a small impact on TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 15.5% fall in measured TFP.

FIGURE 19

PRODUCTIVITY CHANGE IN LAO PDR



Source: Authors' illustration.

TABLE 23

PRODUCTIVITY CHANGE IN LAO PDR

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	0.992	0.970	0.901	0.952	1.000	0.981	0.984	1.008	0.979
3	1963	1.012	0.966	0.865	0.924	1.001	0.995	0.964	0.998	0.966
4	1964	1.314	1.223	1.058	1.063	1.001	0.996	0.979	1.015	1.073
5	1965	1.337	1.217	0.724	1.001	1.001	0.975	0.965	1.014	1.049
6	1966	1.376	1.246	0.631	0.952	1.002	0.990	0.951	1.008	1.002
7	1967	1.502	1.332	0.455	0.949	1.002	0.971	0.960	1.008	1.009
8	1968	1.444	1.274	0.222	0.935	1.002	0.972	1.082	0.977	0.908
9	1969	1.555	1.345	0.121	1.028	1.002	0.974	1.192	0.985	0.897
10	1970	1.552	1.321	0.163	1.060	1.003	0.995	1.205	0.985	0.896
11	1971	1.457	1.222	0.140	1.031	1.003	0.998	1.179	0.984	0.888
12	1972	1.373	1.177	0.128	1.051	1.003	0.990	1.207	0.984	0.891
13	1973	1.367	1.180	0.128	1.116	1.003	0.968	1.292	0.992	0.896
14	1974	1.356	1.186	0.131	1.163	1.004	0.997	1.321	0.990	0.889
15	1975	1.304	1.146	0.122	1.166	1.004	0.994	1.336	0.992	0.882
16	1976	1.197	1.065	0.109	1.101	1.004	0.980	1.317	0.981	0.866
17	1977	1.254	1.134	0.111	1.125	1.004	0.969	1.353	0.982	0.871
18	1978	1.125	1.031	0.097	0.990	1.004	0.999	1.235	0.974	0.821
19	1979	1.392	1.289	0.119	1.187	1.005	0.959	1.360	0.990	0.916
20	1980	1.529	1.427	0.129	1.177	1.005	0.985	1.368	0.980	0.887
21	1981	1.658	1.526	0.098	1.247	1.009	0.991	1.446	0.983	0.878
22	1982	1.651	1.502	0.096	1.228	1.013	0.982	1.419	0.983	0.885
23	1983	1.675	1.492	0.093	1.213	1.017	0.981	1.432	0.985	0.862
24	1984	1.867	1.639	0.100	1.306	1.022	0.992	1.536	0.974	0.861
25	1985	1.994	1.713	0.103	1.376	1.026	0.982	1.621	0.973	0.866
26	1986	2.113	1.773	0.107	1.415	1.030	0.997	1.660	0.978	0.848
27	1987	2.094	1.713	0.104	1.325	1.034	0.966	1.622	0.976	0.837
28	1988	2.045	1.647	0.100	1.297	1.039	0.973	1.608	0.974	0.819
29	1989	2.456	1.934	0.118	1.520	1.043	0.970	1.759	0.979	0.873
30	1990	2.720	2.104	0.128	1.647	1.047	0.996	1.845	0.976	0.877
31	1991	2.485	1.876	0.115	1.462	1.054	0.968	1.784	0.967	0.830
32	1992	2.723	2.019	0.123	1.533	1.061	0.973	1.846	0.969	0.831
33	1993	2.661	1.940	0.117	1.477	1.067	0.945	1.772	0.971	0.851
34	1994	2.881	2.119	0.126	1.581	1.074	0.991	1.848	0.972	0.827
35	1995	2.840	2.078	0.122	1.521	1.081	0.981	1.807	0.961	0.826
36	1996	3.053	2.202	0.129	1.603	1.087	0.997	1.931	0.957	0.800
37	1997	3.500	2.587	0.153	1.855	1.094	0.977	2.184	0.965	0.823
38	1998	3.520	2.624	0.154	2.085	1.101	0.963	2.343	0.976	0.859
39	1999	4.238	3.268	0.195	2.793	1.108	0.998	2.885	0.986	0.888
40	2000	4.897	3.962	0.237	3.204	1.115	0.986	3.363	0.980	0.885
41	2001	5.182	4.313	0.261	3.414	1.116	1.000	3.593	0.974	0.874
42	2002	5.732	4.884	0.300	3.753	1.116	1.003	3.935	0.982	0.867
43	2003	5.789	5.024	0.312	3.827	1.117	0.965	3.920	0.990	0.914

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	5.722	5.076	0.291	3.802	1.118	0.978	3.887	0.988	0.906
45	2005	5.434	4.931	0.258	3.710	1.118	0.987	3.859	0.983	0.886
46	2006	5.325	4.935	0.231	3.618	1.119	0.988	3.922	0.978	0.853
47	2007	5.479	5.203	0.221	3.735	1.120	0.985	4.017	0.977	0.863
48	2008	5.494	5.381	0.206	3.677	1.120	1.006	4.165	0.965	0.812
49	2009	5.877	6.012	0.208	4.008	1.121	0.969	4.592	0.976	0.824
50	2010	6.188	6.553	0.202	4.154	1.122	0.974	4.721	0.975	0.825
51	2011	6.787	7.503	0.206	4.587	1.123	1.010	5.298	0.961	0.794
52	2012	7.052	7.995	0.197	4.636	1.123	0.982	5.394	0.967	0.806
53	2013	7.042	8.220	0.180	4.633	1.124	0.998	5.779	0.947	0.755
54	2014	7.173	8.498	0.165	4.546	1.125	0.958	5.698	0.946	0.783
55	2015	7.998	9.602	0.167	4.904	1.126	0.956	5.672	0.971	0.827
56	2016	8.362	10.164	0.161	4.968	1.126	0.984	5.865	0.964	0.793
57	2017	8.514	10.117	0.148	4.896	1.127	0.998	5.703	0.964	0.791
58	2018	9.180	10.460	0.146	4.948	1.128	0.986	6.207	0.948	0.756
59	2019	10.061	10.960	0.142	5.024	1.129	0.945	5.665	0.969	0.858
60	2020	10.969	11.434	0.150	5.161	1.130	0.955	5.660	0.985	0.859
61	2021	11.776	12.175	0.147	5.406	1.151	0.973	5.823	0.981	0.845

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Malaysia

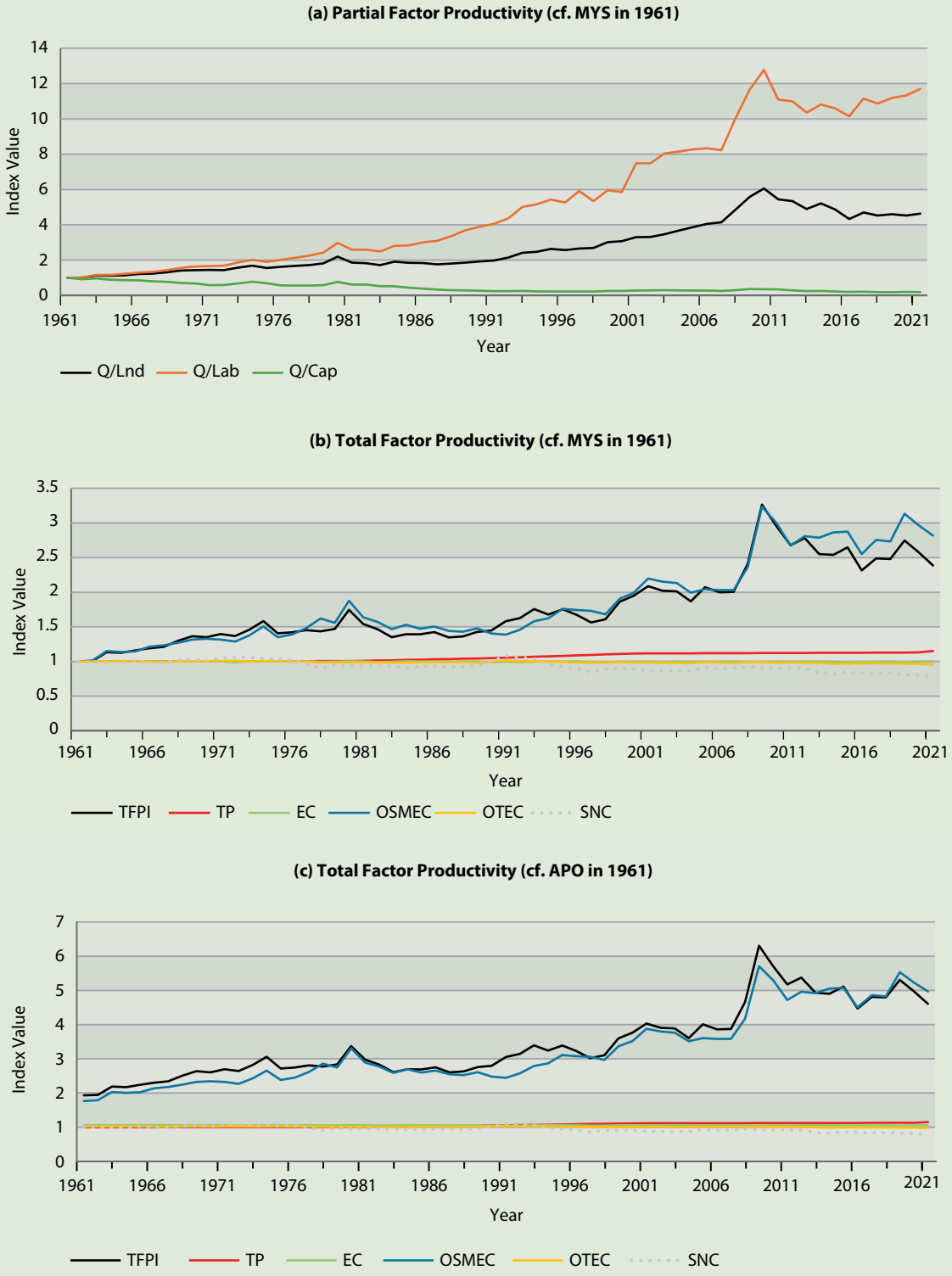
Agriculture is an important part of the Malaysian economy. In 2021, it employed 13.4% (5.4%) of the male (female) labor force and contributed 9.6% to the country's GDP (FAO, 2025a, 2025b). Large scale plantations are mainly used to produce tropical crops that are suitable for export (e.g., palm oil). As the climate in Malaysia is stable, agriculture is rarely affected by extreme weather events. Figure 20 reports the estimated changes in agricultural productivity in Malaysia from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 24. Figure 20(a) indicates that land and labor productivity increased steadily over the sample period; in 2021, the output per unit of land (labor) was 4.638 (11.696) times higher than that in 1961. However, capital productivity fell steadily over the sample period; in 2021, the output per unit of capital was 18.8% of that in 1961. Figure 20(b) indicates that the TFP in Malaysian agriculture was 2.384 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.996 \times 1.151 \times 2.817 \times 0.952 \times 0.775 \\ &= 2.384. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a negligible impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) increased TFP by a factor of 2.817, (iv) lower technical efficiency (OTEC) led to a 4.8% decrease in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 22.5% decrease in measured TFP.

FIGURE 20

PRODUCTIVITY CHANGE IN MALAYSIA



Source: Authors' illustration.

TABLE 24

PRODUCTIVITY CHANGE IN MALAYSIA

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.014	1.019	0.920	1.005	1.000	1.004	1.015	0.999	0.986
3	1963	1.132	1.167	0.963	1.134	1.001	1.001	1.150	1.000	0.984
4	1964	1.123	1.163	0.885	1.125	1.001	1.001	1.137	1.003	0.984
5	1965	1.143	1.224	0.865	1.160	1.001	1.004	1.145	1.002	1.006
6	1966	1.215	1.290	0.851	1.190	1.002	1.002	1.212	0.996	0.982
7	1967	1.242	1.331	0.804	1.211	1.002	1.004	1.235	0.992	0.983
8	1968	1.310	1.434	0.765	1.299	1.002	1.001	1.271	1.000	1.019
9	1969	1.417	1.566	0.699	1.364	1.002	1.001	1.316	1.003	1.030
10	1970	1.437	1.640	0.681	1.349	1.003	1.003	1.328	1.002	1.009
11	1971	1.441	1.660	0.585	1.396	1.003	1.004	1.316	1.005	1.049
12	1972	1.434	1.689	0.593	1.368	1.003	0.990	1.286	1.008	1.063
13	1973	1.575	1.872	0.679	1.458	1.003	1.001	1.376	1.001	1.054
14	1974	1.684	2.015	0.783	1.584	1.004	1.001	1.506	1.004	1.043
15	1975	1.553	1.903	0.691	1.407	1.004	1.003	1.349	1.004	1.031
16	1976	1.625	2.019	0.568	1.422	1.004	0.998	1.389	1.000	1.022
17	1977	1.678	2.135	0.564	1.453	1.004	1.001	1.480	1.000	0.976
18	1978	1.716	2.249	0.556	1.435	1.004	0.993	1.620	0.990	0.897
19	1979	1.818	2.428	0.586	1.470	1.005	0.998	1.557	0.988	0.952
20	1980	2.203	2.979	0.766	1.745	1.005	1.002	1.876	0.990	0.934
21	1981	1.862	2.597	0.616	1.540	1.009	1.000	1.637	0.991	0.941
22	1982	1.826	2.592	0.615	1.465	1.013	0.992	1.571	0.986	0.941
23	1983	1.714	2.494	0.526	1.350	1.017	0.993	1.466	0.984	0.926
24	1984	1.914	2.808	0.514	1.393	1.022	1.002	1.528	0.984	0.905
25	1985	1.850	2.838	0.439	1.393	1.026	1.000	1.471	0.992	0.930
26	1986	1.839	3.002	0.381	1.425	1.030	0.998	1.504	0.990	0.930
27	1987	1.767	3.092	0.332	1.348	1.034	0.993	1.442	0.987	0.922
28	1988	1.806	3.356	0.303	1.362	1.039	0.999	1.430	0.993	0.925
29	1989	1.862	3.692	0.286	1.428	1.043	0.997	1.478	0.988	0.940
30	1990	1.924	3.897	0.263	1.448	1.047	0.985	1.404	0.997	1.002
31	1991	1.986	4.051	0.245	1.582	1.054	0.994	1.386	1.009	1.080
32	1992	2.144	4.359	0.246	1.627	1.061	0.987	1.458	1.006	1.059
33	1993	2.420	5.014	0.260	1.756	1.067	0.998	1.581	1.003	1.040
34	1994	2.474	5.153	0.234	1.678	1.074	0.999	1.624	0.999	0.964
35	1995	2.631	5.427	0.223	1.753	1.081	0.999	1.761	0.995	0.927
36	1996	2.573	5.268	0.218	1.671	1.087	1.000	1.742	0.983	0.898
37	1997	2.662	5.908	0.225	1.564	1.094	0.988	1.732	0.984	0.850
38	1998	2.692	5.346	0.227	1.608	1.101	0.989	1.681	0.983	0.893
39	1999	3.015	5.952	0.255	1.864	1.108	0.996	1.906	0.991	0.894
40	2000	3.073	5.860	0.259	1.950	1.115	0.998	1.994	0.984	0.893
41	2001	3.306	7.484	0.279	2.088	1.116	0.998	2.198	0.987	0.865
42	2002	3.315	7.484	0.284	2.022	1.116	0.990	2.152	0.982	0.866
43	2003	3.463	8.046	0.300	2.012	1.117	0.998	2.134	0.980	0.863

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	3.678	8.148	0.287	1.867	1.118	0.996	1.992	0.977	0.862
45	2005	3.864	8.267	0.280	2.074	1.118	0.996	2.043	0.992	0.919
46	2006	4.056	8.335	0.273	1.999	1.119	0.999	2.031	0.986	0.893
47	2007	4.140	8.229	0.255	2.003	1.120	0.998	2.031	0.978	0.902
48	2008	4.859	10.035	0.297	2.410	1.120	0.993	2.363	0.990	0.926
49	2009	5.585	11.670	0.364	3.265	1.121	0.995	3.235	0.993	0.911
50	2010	6.057	12.768	0.349	2.954	1.122	0.998	3.000	0.982	0.897
51	2011	5.445	11.085	0.339	2.680	1.123	0.995	2.674	0.985	0.911
52	2012	5.348	10.999	0.293	2.781	1.123	0.997	2.810	0.980	0.901
53	2013	4.898	10.352	0.249	2.551	1.124	0.997	2.787	0.979	0.834
54	2014	5.208	10.813	0.254	2.539	1.125	0.996	2.865	0.967	0.818
55	2015	4.878	10.597	0.227	2.647	1.126	0.991	2.875	0.972	0.849
56	2016	4.325	10.153	0.204	2.315	1.126	0.992	2.552	0.974	0.833
57	2017	4.703	11.149	0.210	2.490	1.127	0.995	2.757	0.975	0.826
58	2018	4.522	10.866	0.193	2.481	1.128	0.996	2.732	0.971	0.832
59	2019	4.604	11.181	0.184	2.746	1.129	0.988	3.135	0.967	0.812
60	2020	4.530	11.327	0.201	2.576	1.130	0.996	2.966	0.965	0.800
61	2021	4.638	11.696	0.188	2.384	1.151	0.996	2.817	0.952	0.775

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Mongolia

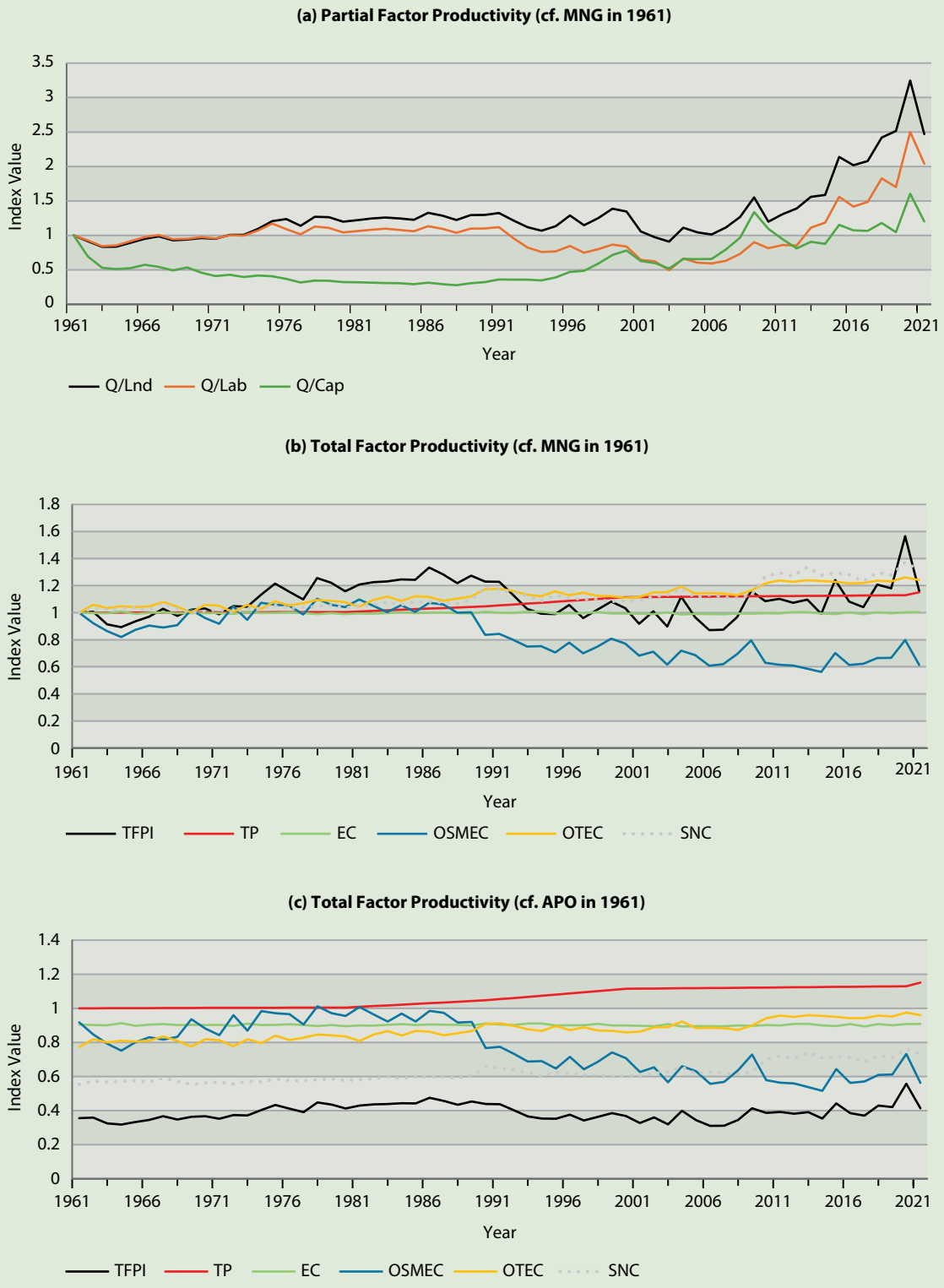
The agriculture sector in Mongolia is heavily focused on nomadic animal husbandry. In 2021, it employed 28.2% (24.3%) of the male (female) labor force and contributed 13.2% to the country's GDP (FAO, 2025a, 2025b). The high altitude of Mongolia makes the climate quite unstable, with extreme fluctuations in temperature. One consequence is that most of the land is allocated to pasture, while less than 3% of the arable land area is used for cropping. Figure 21 reports the estimated changes in agricultural productivity in Mongolia from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 25. Figure 21(a) indicates that land and labor productivity fluctuated considerably but generally increased over the sample period; in 2021, the output per unit of land (labor) was 2.468 (2.040) times higher than that in 1961; in 2021, the output per unit of capital was 20.1% higher than that in 1961. Figure 21(b) indicates that the TFP in Mongolian agriculture was 1.160 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 1.005 \times 1.151 \times 0.614 \times 1.241 \times 1.317 \\ &= 1.160. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a negligible impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) lower scale-mix efficiency (OSMEC) led to a 38.6% fall in TFP, (iv) higher technical efficiency (OTEC) led to a 24.1% increase in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 31.7% increase in measured TFP.

FIGURE 21

PRODUCTIVITY CHANGE IN MONGOLIA



Source: Authors' illustration.

TABLE 25

PRODUCTIVITY CHANGE IN MONGOLIA

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	0.917	0.927	0.695	1.008	1.000	0.997	0.923	1.059	1.034
3	1963	0.834	0.844	0.532	0.914	1.001	0.996	0.865	1.035	1.025
4	1964	0.837	0.855	0.512	0.894	1.001	1.009	0.820	1.046	1.031
5	1965	0.894	0.914	0.524	0.935	1.001	0.991	0.872	1.041	1.037
6	1966	0.951	0.975	0.575	0.971	1.002	0.999	0.905	1.048	1.023
7	1967	0.988	1.005	0.543	1.030	1.002	1.003	0.891	1.079	1.067
8	1968	0.930	0.945	0.493	0.977	1.002	0.996	0.908	1.046	1.030
9	1969	0.939	0.951	0.537	1.022	1.002	0.998	1.021	1.002	0.998
10	1970	0.962	0.975	0.461	1.030	1.003	0.997	0.961	1.059	1.014
11	1971	0.951	0.957	0.410	0.989	1.003	0.998	0.918	1.051	1.024
12	1972	1.008	1.004	0.429	1.048	1.003	0.991	1.047	1.005	1.002
13	1973	1.010	0.997	0.397	1.044	1.003	1.006	0.947	1.059	1.032
14	1974	1.096	1.072	0.419	1.134	1.004	0.997	1.073	1.028	1.027
15	1975	1.207	1.173	0.407	1.216	1.004	0.998	1.059	1.085	1.056
16	1976	1.237	1.089	0.368	1.155	1.004	1.002	1.052	1.053	1.037
17	1977	1.140	1.017	0.317	1.098	1.004	0.997	0.987	1.070	1.038
18	1978	1.270	1.130	0.345	1.256	1.004	0.990	1.103	1.093	1.047
19	1979	1.265	1.109	0.341	1.221	1.005	0.997	1.059	1.088	1.057
20	1980	1.199	1.043	0.322	1.158	1.005	0.989	1.042	1.078	1.037
21	1981	1.221	1.062	0.320	1.208	1.009	0.995	1.098	1.045	1.049
22	1982	1.246	1.082	0.316	1.226	1.013	0.993	1.051	1.094	1.059
23	1983	1.259	1.098	0.310	1.232	1.017	0.998	1.005	1.120	1.078
24	1984	1.245	1.079	0.306	1.245	1.022	1.003	1.056	1.086	1.059
25	1985	1.227	1.060	0.294	1.242	1.026	0.997	1.006	1.121	1.078
26	1986	1.328	1.134	0.315	1.333	1.030	1.000	1.073	1.116	1.080
27	1987	1.287	1.094	0.294	1.283	1.034	1.000	1.062	1.087	1.075
28	1988	1.224	1.038	0.278	1.218	1.039	0.998	1.000	1.103	1.066
29	1989	1.294	1.097	0.306	1.274	1.043	0.994	1.003	1.120	1.094
30	1990	1.298	1.101	0.322	1.231	1.047	1.007	0.836	1.175	1.188
31	1991	1.326	1.121	0.361	1.228	1.054	1.001	0.844	1.177	1.172
32	1992	1.218	0.961	0.360	1.130	1.061	0.997	0.800	1.160	1.153
33	1993	1.119	0.826	0.358	1.028	1.067	1.007	0.750	1.133	1.125
34	1994	1.068	0.761	0.347	0.992	1.074	1.007	0.752	1.122	1.087
35	1995	1.134	0.767	0.391	0.990	1.081	0.994	0.706	1.158	1.127
36	1996	1.288	0.848	0.471	1.057	1.087	0.996	0.780	1.128	1.110
37	1997	1.146	0.749	0.486	0.960	1.094	0.995	0.700	1.148	1.097
38	1998	1.252	0.802	0.590	1.022	1.101	1.004	0.748	1.124	1.099
39	1999	1.388	0.868	0.717	1.081	1.108	0.995	0.808	1.122	1.082
40	2000	1.348	0.838	0.782	1.033	1.115	0.995	0.771	1.111	1.088
41	2001	1.057	0.645	0.630	0.917	1.116	0.992	0.683	1.116	1.087
42	2002	0.973	0.625	0.600	1.010	1.116	0.990	0.712	1.149	1.118
43	2003	0.910	0.496	0.518	0.897	1.117	1.002	0.617	1.152	1.128

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	1.111	0.664	0.659	1.119	1.118	0.987	0.720	1.192	1.182
45	2005	1.045	0.604	0.655	0.966	1.118	0.991	0.687	1.142	1.111
46	2006	1.013	0.593	0.658	0.871	1.119	0.990	0.608	1.145	1.130
47	2007	1.114	0.632	0.797	0.875	1.120	0.989	0.619	1.142	1.117
48	2008	1.268	0.733	0.967	0.968	1.120	0.995	0.694	1.129	1.108
49	2009	1.553	0.901	1.339	1.161	1.121	0.992	0.795	1.164	1.129
50	2010	1.199	0.815	1.097	1.085	1.122	0.996	0.630	1.217	1.266
51	2011	1.308	0.861	0.946	1.102	1.123	0.995	0.615	1.239	1.296
52	2012	1.391	0.852	0.812	1.073	1.123	1.004	0.609	1.228	1.271
53	2013	1.559	1.113	0.907	1.097	1.124	1.004	0.586	1.241	1.337
54	2014	1.587	1.186	0.879	0.992	1.125	0.995	0.562	1.234	1.277
55	2015	2.140	1.560	1.154	1.242	1.126	0.990	0.701	1.228	1.295
56	2016	2.019	1.419	1.073	1.082	1.126	1.003	0.614	1.217	1.281
57	2017	2.079	1.486	1.067	1.041	1.127	0.988	0.623	1.219	1.232
58	2018	2.420	1.828	1.181	1.208	1.128	1.003	0.664	1.238	1.297
59	2019	2.516	1.701	1.047	1.180	1.129	0.996	0.667	1.231	1.279
60	2020	3.246	2.501	1.605	1.566	1.130	1.003	0.798	1.261	1.373
61	2021	2.468	2.040	1.201	1.160	1.151	1.005	0.614	1.241	1.317

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Nepal

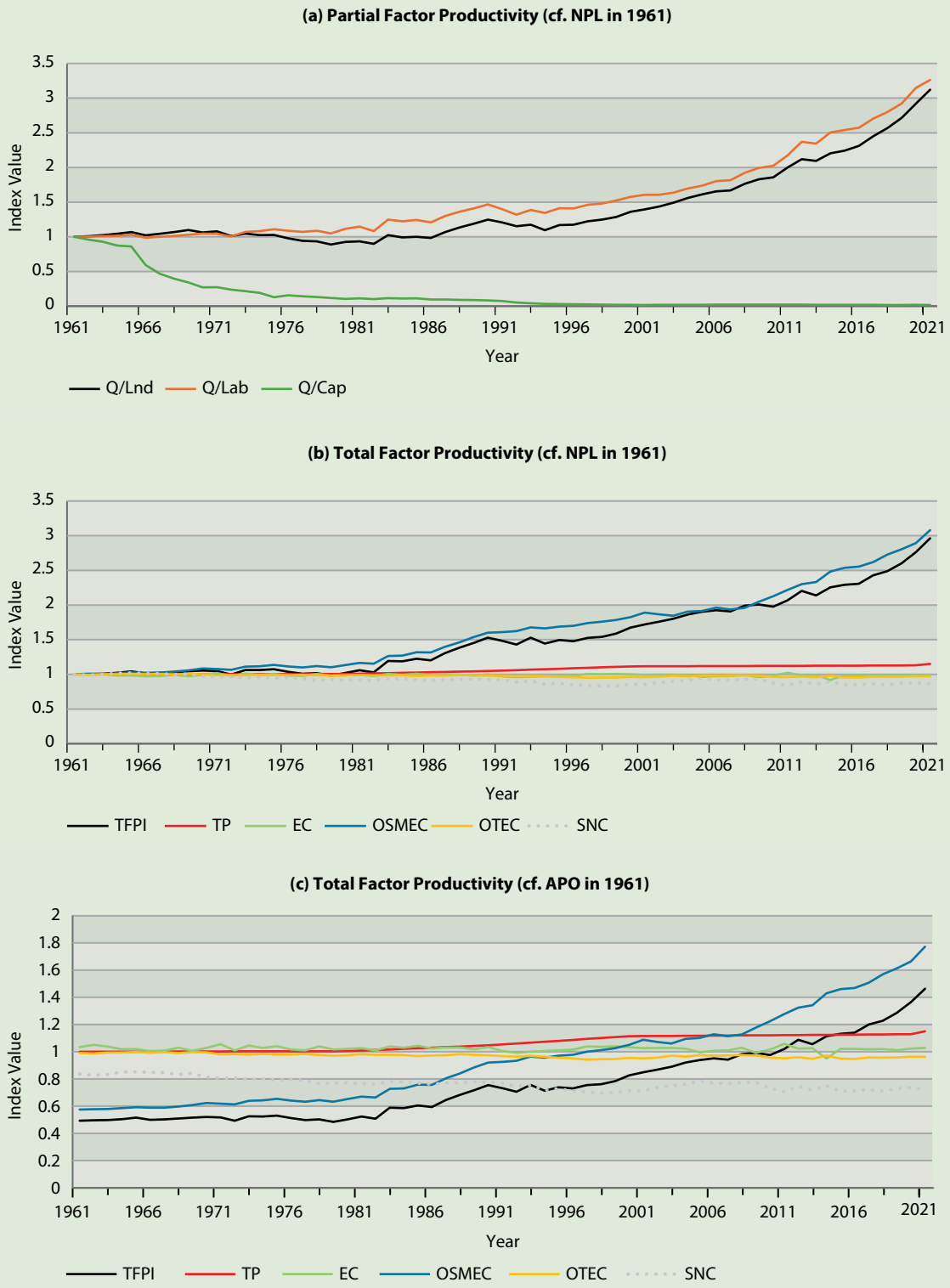
The agriculture sector in Nepal is dominated by smallholder and subsistence farms; most farmers cultivate less than 1 ha. In 2017, it employed 17.2% (38.7%) of the male (female) labor force and contributed 23.6% of the country's GDP (FAO, 2025a, 2025b). Only approximately 20% of the total land area of Nepal can be cultivated. Figure 22 reports the estimated changes in agricultural productivity in Nepal from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 26. Figure 22(a) indicates that land and labor productivity increased over the sample period; in 2021, the output per unit of land (labor) was 3.121 (3.262) times higher than that in 1961. However, capital productivity fell over the sample period; in 2021, the output per unit of capital was 1.9% of that in 1961. Figure 22(b) indicates that the TFP in Nepalese agriculture was 2.962 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.994 \times 1.151 \times 3.080 \times 0.972 \times 0.864 \\ &= 2.962. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a negligible impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) higher scale-mix efficiency (OSMEC) led to a 208% increase in TFP, (iv) lower technical efficiency (OTEC) led to a 2.8% fall in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 13.6% fall in measured TFP.

FIGURE 22

PRODUCTIVITY CHANGE IN NEPAL



Source: Authors' illustration.

TABLE 26

PRODUCTIVITY CHANGE IN NEPAL

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.010	1.002	0.959	1.006	1.000	1.015	1.005	0.996	0.990
3	1963	1.026	1.010	0.928	1.009	1.001	1.003	1.007	1.002	0.997
4	1964	1.043	1.013	0.876	1.021	1.001	0.984	1.018	1.002	1.017
5	1965	1.069	1.030	0.860	1.043	1.001	0.986	1.029	1.007	1.020
6	1966	1.021	0.986	0.593	1.013	1.002	0.971	1.024	1.002	1.015
7	1967	1.043	1.000	0.467	1.019	1.002	0.975	1.025	1.006	1.012
8	1968	1.069	1.014	0.397	1.030	1.002	0.995	1.039	1.000	0.996
9	1969	1.099	1.031	0.343	1.045	1.002	0.973	1.058	1.006	1.006
10	1970	1.064	1.046	0.273	1.055	1.003	0.994	1.084	1.003	0.973
11	1971	1.079	1.043	0.274	1.048	1.003	1.020	1.076	0.989	0.962
12	1972	1.012	1.006	0.239	0.998	1.003	0.976	1.066	0.991	0.964
13	1973	1.047	1.072	0.218	1.063	1.003	1.012	1.110	0.988	0.955
14	1974	1.025	1.081	0.193	1.062	1.004	0.994	1.118	0.993	0.959
15	1975	1.027	1.110	0.131	1.074	1.004	1.007	1.137	0.988	0.946
16	1976	0.979	1.086	0.157	1.038	1.004	0.983	1.115	0.988	0.955
17	1977	0.942	1.070	0.142	1.009	1.004	0.976	1.100	0.993	0.942
18	1978	0.936	1.088	0.133	1.017	1.004	1.005	1.120	0.985	0.914
19	1979	0.889	1.050	0.119	0.982	1.005	0.983	1.101	0.979	0.922
20	1980	0.926	1.115	0.106	1.020	1.005	0.988	1.135	0.983	0.921
21	1981	0.934	1.147	0.114	1.061	1.009	0.992	1.165	0.992	0.917
22	1982	0.898	1.083	0.102	1.027	1.013	0.976	1.154	0.987	0.912
23	1983	1.023	1.249	0.115	1.193	1.017	1.005	1.265	0.986	0.936
24	1984	0.992	1.224	0.110	1.187	1.022	0.995	1.269	0.984	0.934
25	1985	1.000	1.244	0.112	1.226	1.026	1.009	1.318	0.977	0.920
26	1986	0.983	1.208	0.097	1.202	1.030	0.991	1.316	0.982	0.911
27	1987	1.070	1.300	0.096	1.308	1.034	0.998	1.398	0.982	0.923
28	1988	1.133	1.361	0.092	1.385	1.039	0.997	1.460	0.991	0.924
29	1989	1.188	1.410	0.087	1.452	1.043	0.984	1.539	0.986	0.932
30	1990	1.249	1.467	0.084	1.529	1.047	1.000	1.602	0.982	0.927
31	1991	1.208	1.397	0.074	1.483	1.054	0.973	1.610	0.976	0.920
32	1992	1.153	1.319	0.052	1.430	1.061	0.960	1.622	0.973	0.890
33	1993	1.174	1.387	0.043	1.530	1.067	0.968	1.676	0.978	0.904
34	1994	1.096	1.345	0.035	1.445	1.074	0.972	1.662	0.971	0.857
35	1995	1.169	1.413	0.031	1.495	1.081	0.977	1.689	0.963	0.871
36	1996	1.174	1.410	0.027	1.478	1.087	0.980	1.699	0.960	0.850
37	1997	1.225	1.462	0.025	1.527	1.094	1.005	1.739	0.950	0.840
38	1998	1.248	1.481	0.022	1.541	1.101	1.002	1.759	0.954	0.832
39	1999	1.288	1.524	0.021	1.588	1.108	1.006	1.784	0.955	0.836
40	2000	1.360	1.576	0.020	1.673	1.115	0.999	1.826	0.964	0.854
41	2001	1.395	1.607	0.019	1.719	1.116	0.992	1.891	0.960	0.856
42	2002	1.438	1.607	0.019	1.759	1.116	0.994	1.864	0.965	0.882
43	2003	1.491	1.636	0.020	1.803	1.117	0.994	1.844	0.979	0.899

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	1.561	1.696	0.021	1.864	1.118	0.989	1.904	0.973	0.911
45	2005	1.611	1.736	0.021	1.901	1.118	0.962	1.915	0.983	0.939
46	2006	1.656	1.804	0.022	1.926	1.119	0.973	1.962	0.980	0.919
47	2007	1.668	1.817	0.022	1.908	1.120	0.977	1.936	0.982	0.917
48	2008	1.763	1.923	0.024	1.991	1.120	0.995	1.959	0.984	0.926
49	2009	1.830	1.995	0.023	2.008	1.121	0.960	2.047	0.981	0.929
50	2010	1.857	2.023	0.022	1.975	1.122	0.983	2.128	0.964	0.873
51	2011	2.000	2.173	0.022	2.066	1.123	1.023	2.218	0.960	0.844
52	2012	2.119	2.370	0.023	2.204	1.123	0.989	2.300	0.969	0.891
53	2013	2.096	2.344	0.021	2.138	1.124	0.992	2.331	0.957	0.859
54	2014	2.204	2.504	0.021	2.255	1.125	0.919	2.483	0.980	0.897
55	2015	2.242	2.540	0.020	2.292	1.126	0.988	2.537	0.959	0.847
56	2016	2.312	2.573	0.020	2.307	1.126	0.987	2.553	0.955	0.851
57	2017	2.450	2.703	0.019	2.430	1.127	0.985	2.620	0.967	0.864
58	2018	2.568	2.798	0.019	2.487	1.128	0.986	2.726	0.965	0.850
59	2019	2.716	2.922	0.018	2.603	1.129	0.978	2.803	0.966	0.871
60	2020	2.921	3.150	0.020	2.761	1.130	0.989	2.892	0.971	0.880
61	2021	3.121	3.262	0.019	2.962	1.151	0.994	3.080	0.972	0.864

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Pakistan

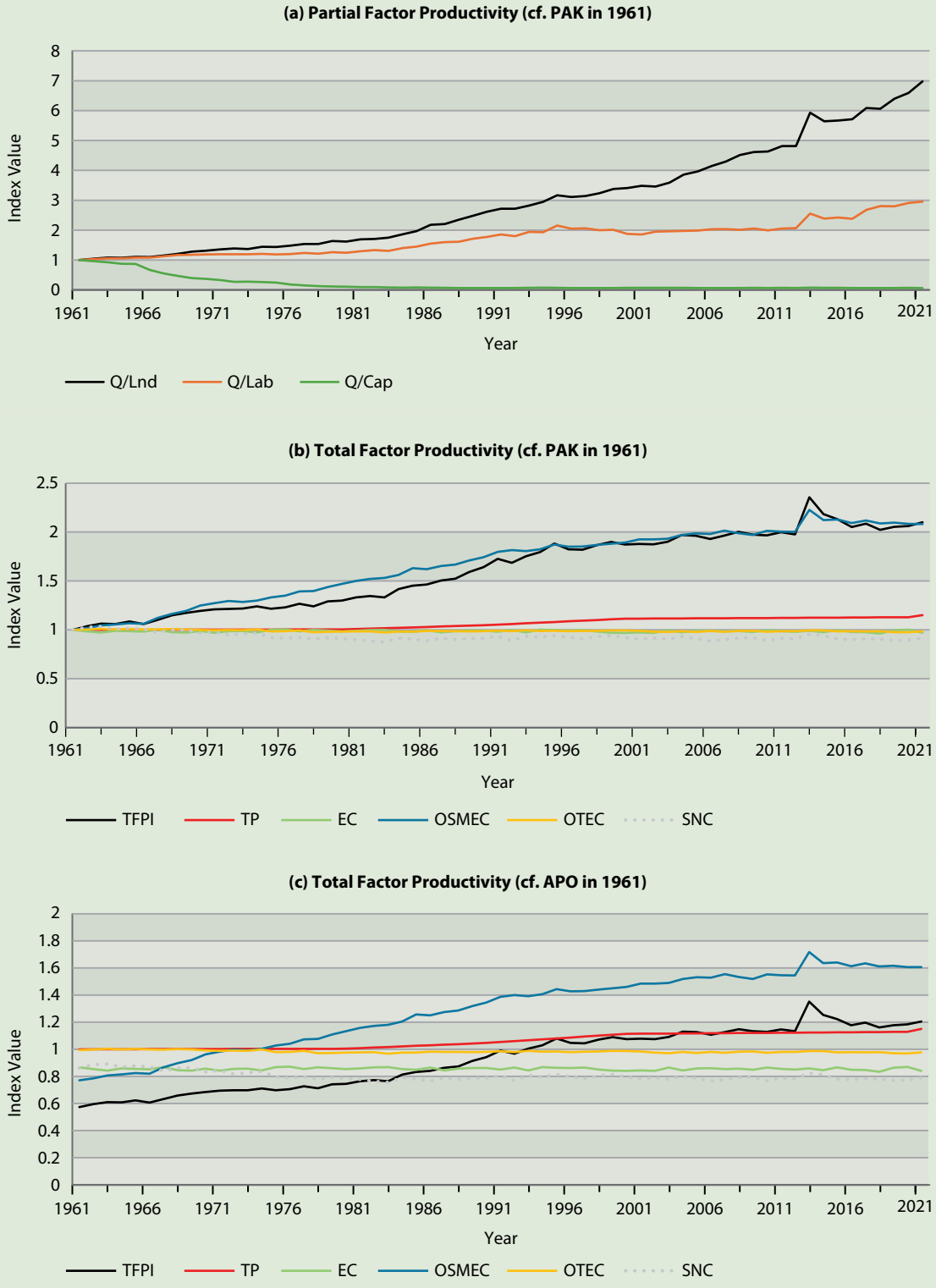
Pakistan is one of the world's largest producers and exporters of food and crop products. For instance, it is the world's fourth largest producer of rice, cotton, and mangoes, and the fifth largest producer of milk and sugarcane. In 2021, its agriculture sector employed 28.3% (67.6%) of the male (female) labor force and contributed 22.7% to the country's GDP (FAO, 2025a, 2025b). Figure 23 reports the estimated changes in agricultural productivity in Pakistan from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 27. Figure 23(a) indicates that land productivity increased by a factor of 6.977 over the reference period. Labor productivity increased, and capital productivity fell significantly during the sample period; in 2021, the output per unit of labor (capital) was 195.6% higher (93.9% lower) than that in 1961. Figure 23(b) indicates that the TFP in Pakistan's agriculture was 2.1 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.970 \times 1.151 \times 2.083 \times 0.985 \times 0.917 \\ &= 2.100. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) accounted for a 3% fall in TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a 108.3% increase in TFP, (iv) lower technical efficiency (OTEC) led to a 1.5% fall in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 8.3% fall in measured TFP.

FIGURE 23

PRODUCTIVITY CHANGE IN PAKISTAN



Source: Authors' illustration.

TABLE 27

PRODUCTIVITY CHANGE IN PAKISTAN

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.042	1.034	0.965	1.037	1.000	0.985	1.019	1.006	1.027
3	1963	1.084	1.058	0.928	1.064	1.001	0.972	1.046	1.011	1.034
4	1964	1.078	1.057	0.877	1.060	1.001	0.991	1.056	1.005	1.007
5	1965	1.107	1.083	0.869	1.086	1.001	0.987	1.069	1.010	1.018
6	1966	1.101	1.080	0.670	1.059	1.002	0.983	1.063	1.005	1.008
7	1967	1.152	1.126	0.554	1.103	1.002	1.002	1.124	1.004	0.974
8	1968	1.205	1.169	0.473	1.149	1.002	0.976	1.164	1.009	1.000
9	1969	1.282	1.175	0.398	1.174	1.002	0.972	1.194	1.005	1.003
10	1970	1.312	1.188	0.370	1.194	1.003	0.988	1.249	0.999	0.966
11	1971	1.357	1.195	0.333	1.210	1.003	0.971	1.273	0.996	0.980
12	1972	1.385	1.195	0.268	1.215	1.003	0.987	1.296	0.998	0.949
13	1973	1.371	1.197	0.278	1.218	1.003	0.989	1.286	0.996	0.958
14	1974	1.442	1.204	0.262	1.240	1.004	0.974	1.300	1.005	0.970
15	1975	1.435	1.187	0.244	1.216	1.004	1.001	1.333	0.985	0.922
16	1976	1.482	1.198	0.186	1.231	1.004	1.006	1.350	0.987	0.915
17	1977	1.540	1.236	0.155	1.267	1.004	0.985	1.392	0.996	0.924
18	1978	1.538	1.215	0.129	1.241	1.004	1.000	1.397	0.977	0.905
19	1979	1.640	1.260	0.117	1.292	1.005	0.992	1.439	0.980	0.919
20	1980	1.618	1.247	0.107	1.299	1.005	0.984	1.470	0.983	0.908
21	1981	1.696	1.294	0.098	1.332	1.009	0.990	1.502	0.984	0.902
22	1982	1.704	1.329	0.094	1.346	1.013	1.000	1.521	0.986	0.886
23	1983	1.752	1.307	0.082	1.332	1.017	1.002	1.531	0.974	0.876
24	1984	1.859	1.399	0.079	1.417	1.022	0.985	1.562	0.982	0.918
25	1985	1.966	1.451	0.083	1.451	1.026	0.978	1.630	0.983	0.903
26	1986	2.180	1.548	0.079	1.464	1.030	0.998	1.621	0.990	0.888
27	1987	2.207	1.600	0.074	1.506	1.034	0.974	1.654	0.988	0.914
28	1988	2.347	1.614	0.068	1.522	1.039	0.988	1.668	0.987	0.901
29	1989	2.481	1.710	0.066	1.592	1.043	0.993	1.711	0.985	0.912
30	1990	2.619	1.774	0.063	1.642	1.047	0.995	1.744	0.987	0.915
31	1991	2.719	1.855	0.066	1.726	1.054	0.981	1.798	0.993	0.935
32	1992	2.717	1.802	0.064	1.685	1.061	0.998	1.815	0.986	0.890
33	1993	2.823	1.941	0.071	1.752	1.067	0.974	1.805	0.996	0.937
34	1994	2.948	1.928	0.079	1.795	1.074	1.002	1.824	0.989	0.924
35	1995	3.164	2.158	0.070	1.882	1.081	0.996	1.873	0.990	0.943
36	1996	3.112	2.046	0.067	1.825	1.087	0.993	1.851	0.986	0.926
37	1997	3.143	2.062	0.066	1.819	1.094	0.998	1.853	0.988	0.909
38	1998	3.237	2.002	0.066	1.867	1.101	0.982	1.868	0.991	0.933
39	1999	3.381	2.011	0.067	1.899	1.108	0.971	1.881	0.995	0.943
40	2000	3.407	1.875	0.073	1.873	1.115	0.969	1.893	0.994	0.921
41	2001	3.484	1.857	0.072	1.879	1.116	0.974	1.925	0.990	0.906
42	2002	3.459	1.951	0.071	1.874	1.116	0.969	1.925	0.983	0.916
43	2003	3.589	1.964	0.071	1.901	1.117	0.998	1.932	0.978	0.903

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	3.858	1.976	0.069	1.971	1.118	0.974	1.970	0.987	0.931
45	2005	3.965	1.986	0.067	1.963	1.118	0.990	1.987	0.979	0.911
46	2006	4.145	2.032	0.068	1.930	1.119	0.993	1.981	0.988	0.888
47	2007	4.298	2.037	0.066	1.963	1.120	0.985	2.015	0.981	0.900
48	2008	4.512	2.015	0.067	2.002	1.120	0.989	1.989	0.989	0.918
49	2009	4.616	2.058	0.068	1.974	1.121	0.979	1.970	0.991	0.922
50	2010	4.633	1.995	0.067	1.967	1.122	0.997	2.013	0.981	0.891
51	2011	4.812	2.056	0.069	1.999	1.123	0.986	2.005	0.987	0.912
52	2012	4.816	2.067	0.067	1.976	1.123	0.980	2.003	0.987	0.908
53	2013	5.929	2.557	0.080	2.356	1.124	0.990	2.227	0.994	0.956
54	2014	5.642	2.388	0.071	2.184	1.125	0.976	2.122	0.995	0.943
55	2015	5.665	2.426	0.069	2.131	1.126	0.999	2.128	0.984	0.904
56	2016	5.713	2.382	0.064	2.052	1.126	0.978	2.092	0.986	0.902
57	2017	6.089	2.679	0.067	2.086	1.127	0.978	2.119	0.984	0.908
58	2018	6.060	2.806	0.066	2.022	1.128	0.962	2.089	0.986	0.905
59	2019	6.396	2.796	0.064	2.053	1.129	0.996	2.095	0.977	0.892
60	2020	6.593	2.913	0.068	2.062	1.130	1.003	2.084	0.976	0.895
61	2021	6.977	2.956	0.061	2.100	1.151	0.970	2.083	0.985	0.917

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

The Philippines

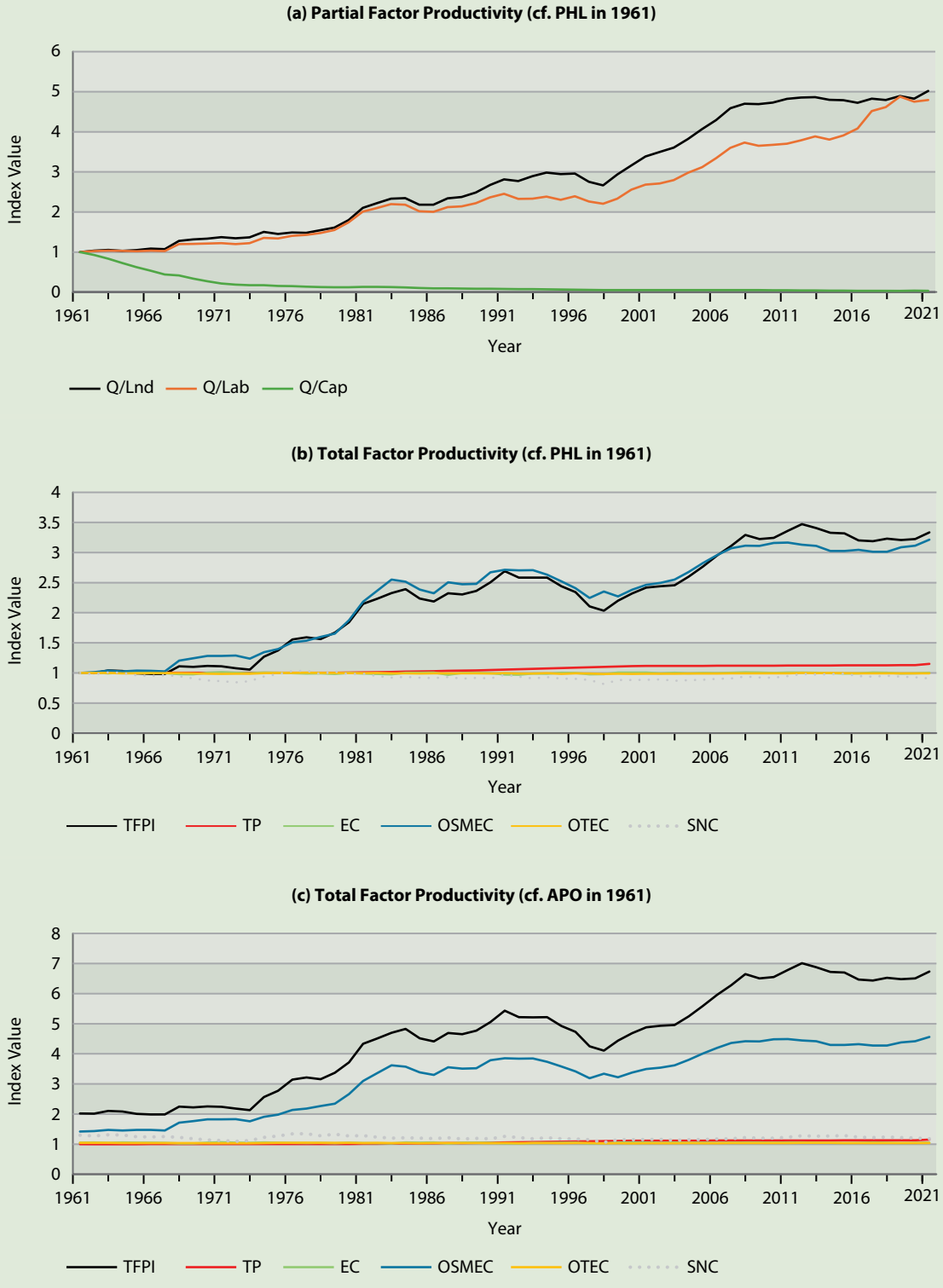
The Philippines is the world's eighth largest producer of rice and the largest producer of coconuts. In 2021, its agriculture sector employed 30.0% (15.3%) of the male (female) labor force and contributed 10.1% to the country's GDP (FAO, 2025a, 2025b). Figure 24 reports the estimated changes in agricultural productivity in the Philippines from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 28. Figure 24(a) indicates that land and labor productivity increased steadily over the sample period; in 2021, the output per unit of land (labor) was 5.020 (4.794) times higher than that in 1961. Capital productivity decreased over the sample period; in 2021, the output per unit of capital was 3.4% of that in 1961. Figure 24(b) indicates that the TFP in Philippine's agriculture was 3.335 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 1.002 \times 1.151 \times 3.214 \times 0.992 \times 0.907 \\ &= 3.335. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a negligible impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a 221.4% increase in TFP, (iv) lower technical efficiency (OTEC) led to a 0.8% fall in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 9.3% fall in measured TFP.

FIGURE 24

PRODUCTIVITY CHANGE IN THE PHILIPPINES



Source: Authors' illustration.

TABLE 28

PRODUCTIVITY CHANGE IN THE PHILIPPINES

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.038	1.027	0.929	0.996	1.000	1.007	1.012	0.999	0.977
3	1963	1.057	1.036	0.834	1.042	1.001	0.993	1.039	1.001	1.009
4	1964	1.034	1.030	0.727	1.031	1.001	1.008	1.026	0.994	1.002
5	1965	1.051	1.024	0.623	0.993	1.001	1.001	1.038	0.994	0.960
6	1966	1.088	1.037	0.535	0.984	1.002	1.002	1.036	0.995	0.952
7	1967	1.073	1.025	0.440	0.984	1.002	0.997	1.026	0.995	0.965
8	1968	1.281	1.198	0.421	1.112	1.002	0.979	1.205	0.995	0.945
9	1969	1.315	1.204	0.340	1.099	1.002	0.977	1.245	0.992	0.909
10	1970	1.337	1.215	0.272	1.116	1.003	1.002	1.284	0.986	0.877
11	1971	1.374	1.223	0.215	1.109	1.003	1.013	1.283	0.984	0.864
12	1972	1.344	1.198	0.191	1.080	1.003	1.003	1.288	0.987	0.844
13	1973	1.370	1.222	0.177	1.054	1.003	0.998	1.239	0.986	0.862
14	1974	1.502	1.356	0.177	1.270	1.004	1.005	1.344	0.996	0.941
15	1975	1.452	1.342	0.159	1.373	1.004	1.002	1.396	0.999	0.979
16	1976	1.488	1.404	0.150	1.556	1.004	0.997	1.506	0.998	1.034
17	1977	1.479	1.429	0.138	1.591	1.004	0.990	1.538	1.004	1.037
18	1978	1.547	1.475	0.128	1.562	1.004	0.993	1.597	0.998	0.983
19	1979	1.613	1.552	0.121	1.670	1.005	0.983	1.654	1.001	1.021
20	1980	1.800	1.745	0.124	1.841	1.005	1.000	1.876	0.998	0.980
21	1981	2.102	2.011	0.134	2.147	1.009	0.991	2.183	0.995	0.988
22	1982	2.218	2.100	0.131	2.234	1.013	0.985	2.366	0.999	0.947
23	1983	2.334	2.195	0.128	2.328	1.017	0.977	2.551	0.995	0.923
24	1984	2.346	2.183	0.119	2.392	1.022	1.005	2.516	0.992	0.933
25	1985	2.180	2.018	0.103	2.235	1.026	1.002	2.385	0.989	0.922
26	1986	2.183	2.006	0.095	2.186	1.030	1.006	2.323	0.993	0.914
27	1987	2.343	2.123	0.094	2.325	1.034	0.969	2.506	0.994	0.931
28	1988	2.376	2.140	0.089	2.305	1.039	0.999	2.473	0.993	0.905
29	1989	2.488	2.221	0.086	2.363	1.043	1.003	2.479	0.992	0.918
30	1990	2.673	2.363	0.085	2.505	1.047	0.996	2.671	0.990	0.908
31	1991	2.816	2.456	0.083	2.690	1.054	0.975	2.713	0.995	0.969
32	1992	2.773	2.327	0.077	2.583	1.061	0.969	2.705	0.991	0.938
33	1993	2.896	2.331	0.075	2.582	1.067	0.991	2.708	0.991	0.910
34	1994	2.985	2.384	0.073	2.583	1.074	0.986	2.633	0.995	0.931
35	1995	2.944	2.303	0.068	2.439	1.081	1.003	2.523	0.985	0.906
36	1996	2.960	2.393	0.065	2.344	1.087	1.001	2.406	0.992	0.902
37	1997	2.753	2.264	0.057	2.105	1.094	0.978	2.246	0.991	0.884
38	1998	2.663	2.208	0.052	2.035	1.101	0.980	2.354	0.982	0.816
39	1999	2.936	2.332	0.054	2.199	1.108	1.006	2.270	0.985	0.883
40	2000	3.163	2.556	0.055	2.319	1.115	1.007	2.380	0.983	0.883
41	2001	3.386	2.682	0.055	2.417	1.116	1.005	2.464	0.987	0.886
42	2002	3.499	2.712	0.053	2.442	1.116	0.994	2.494	0.988	0.893
43	2003	3.604	2.797	0.053	2.456	1.117	1.005	2.550	0.988	0.869

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	3.820	2.979	0.053	2.598	1.118	0.995	2.678	0.991	0.881
45	2005	4.071	3.117	0.053	2.766	1.118	0.998	2.824	0.990	0.887
46	2006	4.293	3.345	0.054	2.952	1.119	0.998	2.956	0.991	0.903
47	2007	4.587	3.599	0.053	3.110	1.120	1.003	3.072	0.993	0.908
48	2008	4.701	3.730	0.053	3.291	1.120	1.009	3.114	0.995	0.940
49	2009	4.691	3.654	0.053	3.223	1.121	1.007	3.110	0.994	0.924
50	2010	4.729	3.674	0.049	3.245	1.122	1.000	3.159	0.994	0.922
51	2011	4.821	3.705	0.048	3.360	1.123	1.006	3.166	0.993	0.947
52	2012	4.854	3.789	0.046	3.471	1.123	1.006	3.130	0.999	0.983
53	2013	4.864	3.887	0.043	3.405	1.124	1.002	3.111	0.997	0.974
54	2014	4.799	3.804	0.040	3.327	1.125	0.997	3.027	0.999	0.980
55	2015	4.788	3.907	0.038	3.318	1.126	0.990	3.027	0.997	0.987
56	2016	4.723	4.081	0.036	3.202	1.126	0.992	3.044	0.993	0.947
57	2017	4.826	4.516	0.036	3.188	1.127	1.006	3.012	0.994	0.939
58	2018	4.793	4.615	0.034	3.231	1.128	1.002	3.012	0.994	0.955
59	2019	4.891	4.879	0.033	3.209	1.129	0.990	3.086	0.993	0.937
60	2020	4.825	4.752	0.038	3.223	1.130	0.994	3.112	0.992	0.929
61	2021	5.020	4.794	0.034	3.335	1.151	1.002	3.214	0.992	0.907

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Sri Lanka

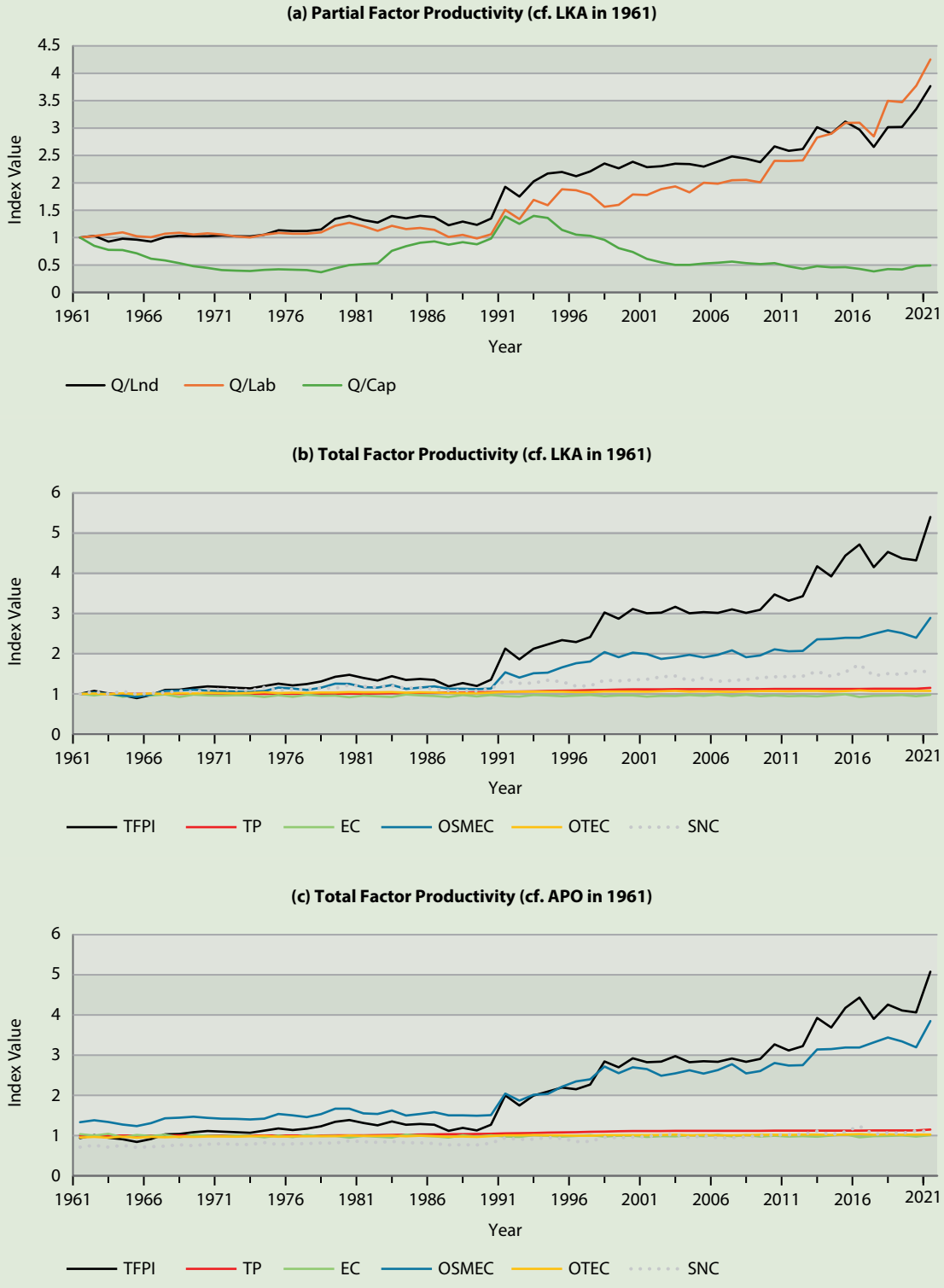
In 2021, the agriculture sector in Sri Lanka employed 26.3% (29.2%) of the male (female) labor force and contributed 8.8% to the country's GDP (FAO, 2025a, 2025b). Rice is the main agricultural crop, accounting for 34% of the total cultivated area. Tea is also an important product for the export market. Figure 25 reports the estimated changes in Sri Lanka's agricultural productivity from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 29. Figure 25(a) indicates that land and labor productivity fluctuated but generally increased over the sample period; in 2021, the output per unit of land (labor) was 3.766 times (4.253) higher than that in 1961. However, capital productivity generally fell over the sample period; in 2021, the output per unit of capital was 49.4% of that in 1961. Figure 25(b) indicates that the TFP of Sri Lankan agriculture was 5.402 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.978 \times 1.151 \times 2.892 \times 1.073 \times 1.546 \\ &= 5.402. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a negative impact of 2.2% on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a 189.2% increase in TFP, (iv) higher technical efficiency (OTEC) led to a 7.3% increase in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 54.6% increase in measured TFP.

FIGURE 25

PRODUCTIVITY CHANGE IN SRI LANKA



Source: Authors' illustration.

TABLE 29

PRODUCTIVITY CHANGE IN SRI LANKA

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.035	1.031	0.851	1.076	1.000	0.965	1.037	1.012	1.062
3	1963	0.929	1.060	0.776	1.010	1.001	1.009	1.005	0.993	1.004
4	1964	0.981	1.097	0.775	0.966	1.001	0.931	0.956	1.017	1.066
5	1965	0.963	1.026	0.712	0.896	1.001	0.981	0.929	0.991	0.991
6	1966	0.929	1.008	0.614	0.974	1.002	0.960	0.985	1.011	1.019
7	1967	1.009	1.072	0.586	1.099	1.002	0.986	1.073	1.003	1.033
8	1968	1.032	1.088	0.536	1.107	1.002	0.925	1.086	1.016	1.082
9	1969	1.028	1.057	0.479	1.154	1.002	0.980	1.103	1.014	1.050
10	1970	1.025	1.077	0.448	1.186	1.003	0.965	1.083	1.025	1.104
11	1971	1.040	1.059	0.410	1.172	1.003	0.957	1.066	1.021	1.121
12	1972	1.025	1.022	0.396	1.155	1.003	0.970	1.063	1.018	1.098
13	1973	1.022	1.004	0.390	1.139	1.003	0.965	1.051	1.027	1.090
14	1974	1.054	1.055	0.410	1.198	1.004	0.924	1.069	1.040	1.162
15	1975	1.136	1.087	0.424	1.254	1.004	0.969	1.156	1.020	1.093
16	1976	1.122	1.073	0.417	1.212	1.004	0.928	1.132	1.030	1.116
17	1977	1.120	1.070	0.410	1.247	1.004	0.980	1.098	1.028	1.122
18	1978	1.148	1.097	0.369	1.310	1.004	0.953	1.153	1.036	1.145
19	1979	1.343	1.217	0.441	1.427	1.005	0.960	1.254	1.035	1.140
20	1980	1.399	1.271	0.499	1.476	1.005	0.918	1.253	1.047	1.220
21	1981	1.321	1.210	0.519	1.397	1.009	0.960	1.168	1.039	1.188
22	1982	1.276	1.126	0.530	1.335	1.013	0.937	1.157	1.041	1.167
23	1983	1.396	1.216	0.761	1.441	1.017	0.922	1.221	1.046	1.202
24	1984	1.351	1.157	0.843	1.349	1.022	0.989	1.126	1.030	1.151
25	1985	1.398	1.178	0.908	1.371	1.026	0.962	1.157	1.041	1.153
26	1986	1.373	1.141	0.930	1.350	1.030	0.950	1.187	1.035	1.122
27	1987	1.226	1.014	0.872	1.189	1.034	0.922	1.131	1.020	1.080
28	1988	1.292	1.050	0.918	1.269	1.039	0.971	1.131	1.024	1.086
29	1989	1.233	0.985	0.880	1.199	1.043	0.941	1.122	1.015	1.074
30	1990	1.349	1.061	0.985	1.353	1.047	0.973	1.133	1.032	1.136
31	1991	1.928	1.506	1.388	2.131	1.054	0.942	1.537	1.053	1.326
32	1992	1.749	1.337	1.253	1.861	1.061	0.933	1.406	1.056	1.267
33	1993	2.027	1.690	1.397	2.123	1.067	0.975	1.516	1.058	1.272
34	1994	2.172	1.591	1.361	2.229	1.074	0.961	1.529	1.055	1.339
35	1995	2.199	1.883	1.141	2.337	1.081	0.946	1.663	1.054	1.304
36	1996	2.123	1.864	1.054	2.288	1.087	0.959	1.765	1.044	1.191
37	1997	2.210	1.788	1.035	2.417	1.094	0.974	1.805	1.046	1.200
38	1998	2.355	1.563	0.959	3.025	1.101	0.944	2.042	1.061	1.344
39	1999	2.266	1.600	0.810	2.872	1.108	0.964	1.916	1.060	1.323
40	2000	2.384	1.788	0.740	3.112	1.115	0.961	2.028	1.061	1.350
41	2001	2.286	1.778	0.614	3.005	1.116	0.936	1.995	1.058	1.363
42	2002	2.302	1.887	0.550	3.022	1.116	0.955	1.869	1.064	1.425
43	2003	2.351	1.935	0.503	3.166	1.117	0.950	1.915	1.075	1.449

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	2.343	1.828	0.504	3.007	1.118	0.974	1.971	1.054	1.330
45	2005	2.295	2.001	0.529	3.034	1.118	0.955	1.910	1.064	1.398
46	2006	2.387	1.985	0.542	3.016	1.119	0.985	1.975	1.056	1.313
47	2007	2.484	2.046	0.561	3.104	1.120	0.947	2.087	1.053	1.333
48	2008	2.442	2.054	0.535	3.019	1.120	0.978	1.914	1.061	1.357
49	2009	2.377	2.008	0.518	3.095	1.121	0.942	1.956	1.070	1.400
50	2010	2.665	2.403	0.536	3.477	1.122	0.964	2.108	1.068	1.428
51	2011	2.584	2.400	0.475	3.319	1.123	0.943	2.059	1.065	1.430
52	2012	2.617	2.407	0.430	3.433	1.123	0.954	2.069	1.073	1.443
53	2013	3.018	2.828	0.480	4.179	1.124	0.939	2.359	1.074	1.562
54	2014	2.900	2.896	0.459	3.923	1.125	0.965	2.369	1.063	1.434
55	2015	3.118	3.094	0.460	4.442	1.126	0.994	2.399	1.073	1.543
56	2016	2.969	3.095	0.431	4.718	1.126	0.926	2.397	1.087	1.735
57	2017	2.653	2.850	0.385	4.151	1.127	0.951	2.494	1.071	1.449
58	2018	3.018	3.496	0.428	4.534	1.128	0.960	2.584	1.077	1.503
59	2019	3.020	3.474	0.420	4.375	1.129	0.973	2.512	1.068	1.484
60	2020	3.349	3.776	0.487	4.323	1.130	0.943	2.399	1.075	1.574
61	2021	3.766	4.253	0.494	5.402	1.151	0.978	2.892	1.073	1.546

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Thailand

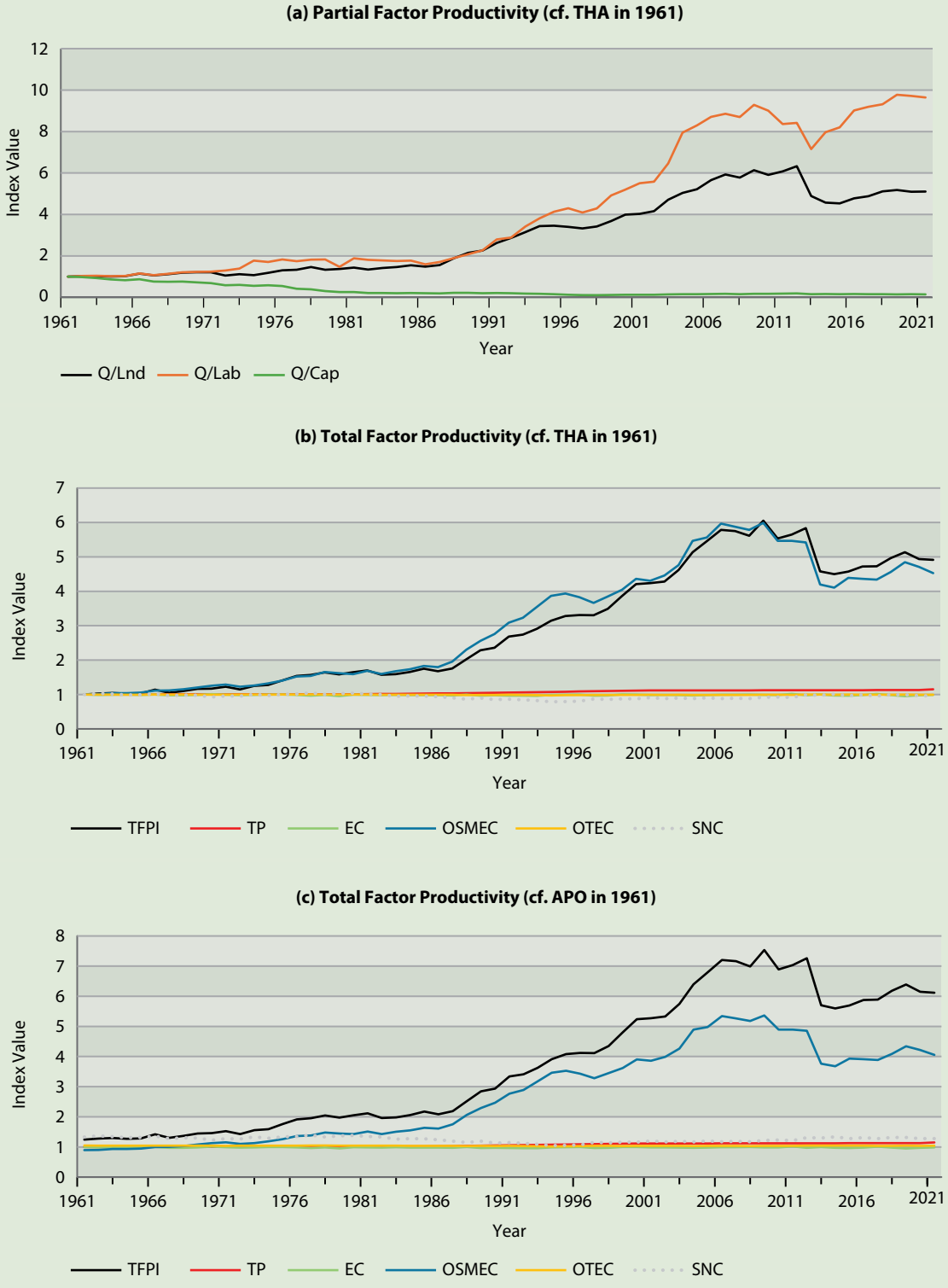
In 2021, the agriculture sector in Thailand employed 34.8% (28.4%) of the male (female) labor force and contributed 8.7% to the country's GDP (FAO, 2025a, 2025b). Thailand is a successful exporter of rice. Other major commodities include rubber, sugar, and fish and fishery products. Figure 26 reports the estimated changes in agricultural productivity in Thailand from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 30. Figure 26(a) indicates that land and labor productivity increased steadily over the sample period; in 2021, the output per unit of land (labor) was 5.1 (9.643) times higher than that in 1961. However, capital productivity fell significantly over the sample period; in 2021, the output per unit of capital was 14.4% of that in 1961. Figure 26(b) indicates that the TFP in Thai agriculture was 4.915 times higher in 2015 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.986 \times 1.151 \times 4.525 \times 0.995 \times 0.962 \\ &= 4.915. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a negative impact of 1.4% on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) increased TFP by a factor of 4.525, (iv) lower technical efficiency (OTEC) led to a 0.5% fall in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 3.8% fall in measured TFP.

FIGURE 26

PRODUCTIVITY CHANGE IN THAILAND



Source: Authors' illustration.

TABLE 30

PRODUCTIVITY CHANGE IN THAILAND

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.022	1.031	0.975	1.027	1.000	0.988	1.008	0.999	1.032
3	1963	1.021	1.046	0.934	1.045	1.001	0.995	1.038	0.998	1.013
4	1964	1.002	1.021	0.862	1.019	1.001	0.996	1.038	0.995	0.989
5	1965	1.021	1.037	0.826	1.032	1.001	0.988	1.056	0.996	0.993
6	1966	1.142	1.160	0.871	1.141	1.002	0.998	1.113	0.998	1.028
7	1967	1.060	1.075	0.761	1.049	1.002	0.975	1.121	0.996	0.962
8	1968	1.121	1.135	0.756	1.102	1.002	0.974	1.151	0.998	0.982
9	1969	1.195	1.207	0.757	1.161	1.002	0.989	1.206	0.994	0.977
10	1970	1.208	1.229	0.727	1.170	1.003	1.009	1.257	0.994	0.925
11	1971	1.213	1.235	0.685	1.227	1.003	0.995	1.290	0.993	0.960
12	1972	1.053	1.296	0.582	1.145	1.003	0.982	1.227	0.996	0.951
13	1973	1.119	1.387	0.604	1.252	1.003	0.985	1.263	0.997	1.005
14	1974	1.069	1.775	0.559	1.277	1.004	0.997	1.322	0.994	0.971
15	1975	1.187	1.704	0.586	1.411	1.004	0.999	1.403	0.996	1.007
16	1976	1.309	1.825	0.544	1.537	1.004	0.989	1.524	0.999	1.017
17	1977	1.332	1.747	0.416	1.569	1.004	0.965	1.541	1.002	1.048
18	1978	1.460	1.818	0.383	1.643	1.004	0.987	1.652	1.001	1.002
19	1979	1.336	1.827	0.303	1.585	1.005	0.952	1.618	0.996	1.028
20	1980	1.368	1.473	0.252	1.646	1.005	0.990	1.592	0.999	1.040
21	1981	1.437	1.884	0.260	1.701	1.009	0.985	1.688	0.999	1.015
22	1982	1.339	1.814	0.212	1.576	1.013	0.980	1.596	0.994	1.000
23	1983	1.416	1.780	0.209	1.593	1.017	0.990	1.677	0.994	0.949
24	1984	1.464	1.757	0.200	1.652	1.022	0.980	1.734	0.991	0.961
25	1985	1.550	1.770	0.206	1.748	1.026	0.983	1.829	0.993	0.955
26	1986	1.487	1.597	0.200	1.676	1.030	0.979	1.795	0.991	0.934
27	1987	1.554	1.709	0.194	1.756	1.034	0.973	1.956	0.991	0.900
28	1988	1.881	1.892	0.216	2.023	1.039	0.997	2.303	0.984	0.862
29	1989	2.151	2.078	0.219	2.284	1.043	0.967	2.558	0.988	0.896
30	1990	2.257	2.264	0.204	2.360	1.047	0.976	2.757	0.985	0.850
31	1991	2.625	2.789	0.212	2.684	1.054	0.965	3.088	0.990	0.863
32	1992	2.867	2.891	0.198	2.742	1.061	0.962	3.229	0.986	0.844
33	1993	3.150	3.422	0.186	2.911	1.067	0.958	3.547	0.980	0.820
34	1994	3.438	3.813	0.175	3.145	1.074	0.989	3.866	0.971	0.789
35	1995	3.455	4.127	0.152	3.279	1.081	0.991	3.936	0.980	0.794
36	1996	3.404	4.298	0.129	3.307	1.087	1.001	3.827	0.984	0.807
37	1997	3.328	4.090	0.109	3.303	1.094	0.963	3.660	0.988	0.867
38	1998	3.419	4.287	0.111	3.490	1.101	0.972	3.852	0.989	0.856
39	1999	3.680	4.917	0.118	3.859	1.108	1.002	4.042	0.987	0.871
40	2000	3.996	5.196	0.126	4.209	1.115	1.000	4.362	0.990	0.875
41	2001	4.024	5.504	0.125	4.236	1.116	0.984	4.306	0.990	0.905
42	2002	4.159	5.586	0.128	4.282	1.116	0.988	4.457	0.989	0.880
43	2003	4.708	6.463	0.142	4.617	1.117	0.979	4.762	0.992	0.894

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	5.042	7.953	0.150	5.137	1.118	0.970	5.466	0.985	0.880
45	2005	5.220	8.299	0.153	5.456	1.118	0.982	5.561	0.988	0.904
46	2006	5.661	8.705	0.164	5.785	1.119	0.994	5.968	0.988	0.882
47	2007	5.924	8.858	0.169	5.753	1.120	0.991	5.875	0.989	0.892
48	2008	5.780	8.697	0.158	5.615	1.120	0.997	5.785	0.985	0.881
49	2009	6.133	9.287	0.173	6.053	1.121	0.988	5.988	0.994	0.918
50	2010	5.909	9.003	0.171	5.536	1.122	0.984	5.466	0.991	0.926
51	2011	6.076	8.359	0.180	5.648	1.123	1.019	5.465	0.987	0.915
52	2012	6.328	8.420	0.191	5.835	1.123	0.976	5.421	0.996	0.986
53	2013	4.888	7.150	0.150	4.579	1.124	0.998	4.196	0.997	0.976
54	2014	4.572	7.964	0.158	4.496	1.125	0.971	4.104	0.995	1.008
55	2015	4.535	8.198	0.155	4.571	1.126	0.963	4.388	0.998	0.963
56	2016	4.774	9.014	0.161	4.719	1.126	0.980	4.364	0.994	0.986
57	2017	4.882	9.191	0.155	4.728	1.127	1.014	4.339	0.993	0.961
58	2018	5.113	9.321	0.150	4.964	1.128	0.981	4.562	0.993	0.991
59	2019	5.179	9.775	0.147	5.135	1.129	0.951	4.845	0.996	0.992
60	2020	5.092	9.719	0.158	4.938	1.130	0.974	4.708	0.991	0.962
61	2021	5.100	9.643	0.144	4.915	1.151	0.986	4.525	0.995	0.962

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Turkiye

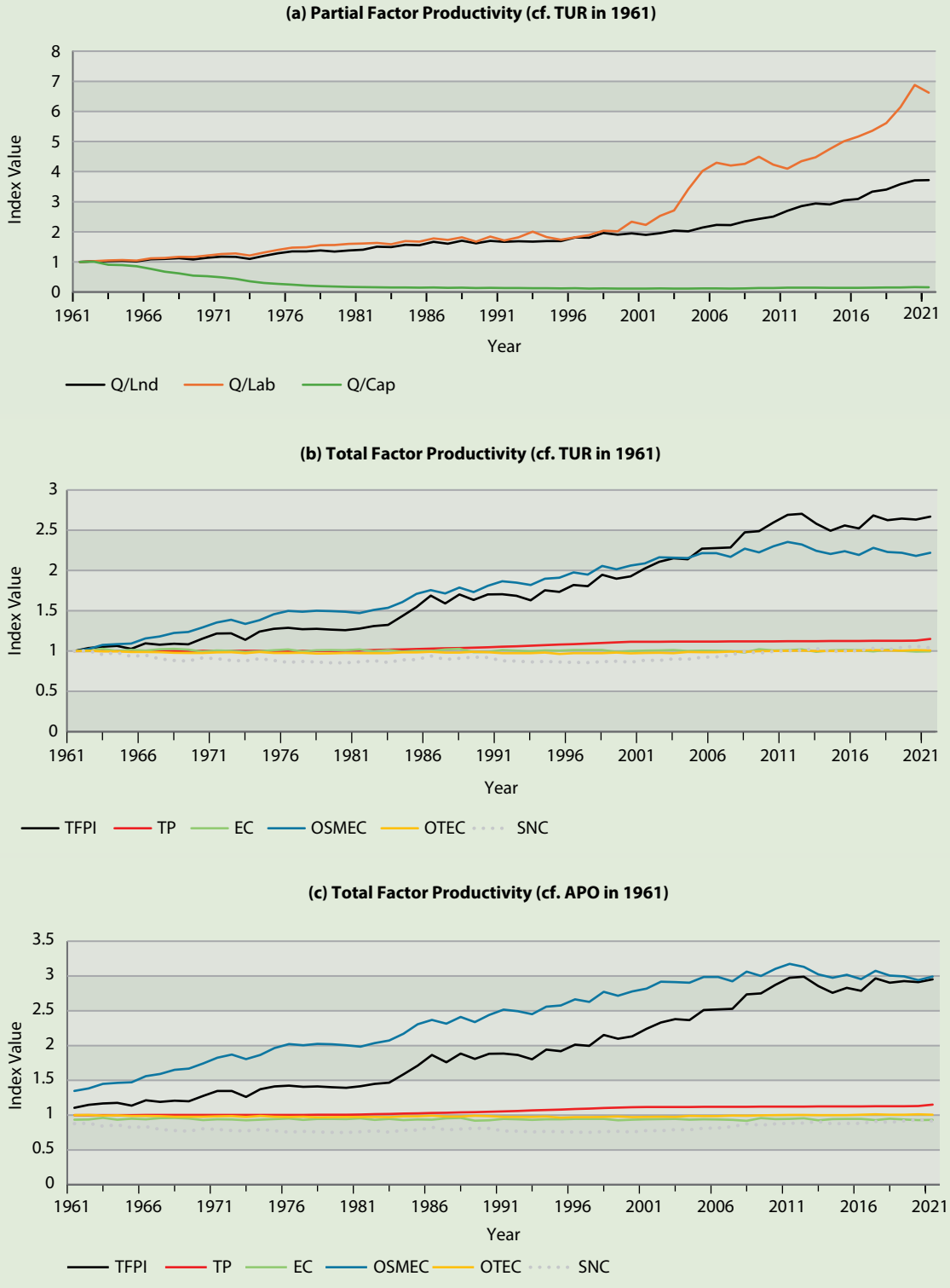
Turkiye has an important agriculture sector, characterized by diverse climate and extensive arable land. The sector plays a pivotal role in regional and global food markets. In 2021, it employed 14.6% (22.7%) of the male (female) labor force and contributed 5.5% to the country's GDP (FAO, 2025a, 2025b). Figure 27 reports the estimated changes in agricultural productivity in Turkiye from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 31. Figure 27(a) indicates that land and labor productivity increased over the sample period; in 2021, the output per unit of land (labor) was 3.718 (6.620) times higher than that in 1961. However, capital productivity fell over the sample period; in 2021, the output per unit of capital was 15.9% of that in 1961. Figure 27(b) indicates that the TFP in Turkish agriculture was 2.670 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.996 \times 1.151 \times 2.220 \times 1.008 \times 1.041 \\ &= 2.670. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had almost no impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) increased TFP by a factor of 2.220, (iv) higher technical efficiency (OTEC) led to a 0.8% increase in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 4.1% increase in measured TFP.

FIGURE 27

PRODUCTIVITY CHANGE IN TURKIYE



Source: Authors' illustration.

TABLE 31

PRODUCTIVITY CHANGE IN TURKIYE

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.023	1.024	1.008	1.038	1.000	1.002	1.026	1.005	1.005
3	1963	1.024	1.049	0.908	1.056	1.001	1.029	1.076	0.997	0.956
4	1964	1.038	1.060	0.892	1.063	1.001	1.001	1.086	0.997	0.980
5	1965	1.022	1.044	0.859	1.027	1.001	1.017	1.093	0.990	0.933
6	1966	1.088	1.122	0.770	1.097	1.002	1.007	1.158	0.988	0.951
7	1967	1.103	1.132	0.678	1.078	1.002	1.024	1.181	0.986	0.904
8	1968	1.128	1.170	0.619	1.092	1.002	1.028	1.225	0.978	0.885
9	1969	1.080	1.165	0.548	1.084	1.002	1.019	1.237	0.978	0.877
10	1970	1.136	1.211	0.525	1.155	1.003	0.994	1.294	0.978	0.915
11	1971	1.174	1.262	0.489	1.218	1.003	1.008	1.354	0.984	0.905
12	1972	1.169	1.284	0.437	1.219	1.003	1.003	1.388	0.986	0.885
13	1973	1.101	1.213	0.359	1.141	1.003	0.990	1.339	0.975	0.880
14	1974	1.200	1.311	0.304	1.242	1.004	0.999	1.384	0.989	0.906
15	1975	1.286	1.400	0.269	1.277	1.004	1.010	1.458	0.978	0.884
16	1976	1.347	1.477	0.244	1.289	1.004	1.020	1.500	0.977	0.860
17	1977	1.347	1.490	0.215	1.272	1.004	0.997	1.488	0.979	0.871
18	1978	1.383	1.554	0.196	1.277	1.004	1.012	1.502	0.969	0.864
19	1979	1.347	1.561	0.181	1.266	1.005	1.013	1.497	0.971	0.855
20	1980	1.381	1.597	0.170	1.260	1.005	1.010	1.488	0.977	0.854
21	1981	1.406	1.612	0.167	1.280	1.009	1.020	1.473	0.974	0.867
22	1982	1.503	1.634	0.160	1.311	1.013	0.998	1.510	0.974	0.881
23	1983	1.496	1.586	0.151	1.325	1.017	1.013	1.539	0.973	0.858
24	1984	1.569	1.690	0.151	1.434	1.022	0.994	1.609	0.984	0.892
25	1985	1.557	1.672	0.145	1.549	1.026	1.003	1.710	0.985	0.893
26	1986	1.671	1.782	0.149	1.688	1.030	1.000	1.758	0.992	0.940
27	1987	1.605	1.728	0.141	1.592	1.034	1.021	1.716	0.981	0.895
28	1988	1.705	1.821	0.146	1.705	1.039	1.027	1.788	0.981	0.911
29	1989	1.619	1.677	0.136	1.636	1.043	0.986	1.734	0.992	0.925
30	1990	1.699	1.844	0.139	1.703	1.047	0.990	1.810	0.986	0.921
31	1991	1.670	1.713	0.135	1.705	1.054	1.012	1.867	0.974	0.879
32	1992	1.685	1.821	0.131	1.687	1.061	1.007	1.851	0.974	0.876
33	1993	1.673	2.008	0.127	1.631	1.067	0.998	1.819	0.974	0.864
34	1994	1.690	1.825	0.126	1.755	1.074	1.008	1.898	0.981	0.871
35	1995	1.693	1.740	0.122	1.735	1.081	1.006	1.912	0.965	0.865
36	1996	1.809	1.818	0.125	1.821	1.087	1.013	1.976	0.974	0.860
37	1997	1.803	1.892	0.114	1.806	1.094	1.014	1.950	0.973	0.858
38	1998	1.961	2.036	0.122	1.948	1.101	1.014	2.058	0.975	0.869
39	1999	1.904	2.020	0.116	1.898	1.108	0.992	2.015	0.981	0.873
40	2000	1.946	2.335	0.116	1.928	1.115	1.001	2.061	0.972	0.862
41	2001	1.900	2.230	0.115	2.027	1.116	1.006	2.090	0.976	0.886
42	2002	1.955	2.532	0.118	2.108	1.116	1.009	2.165	0.979	0.883
43	2003	2.044	2.712	0.118	2.153	1.117	1.013	2.161	0.975	0.903

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	2.020	3.416	0.117	2.139	1.118	1.001	2.154	0.989	0.898
45	2005	2.144	4.020	0.123	2.272	1.118	1.006	2.216	0.986	0.924
46	2006	2.230	4.295	0.123	2.280	1.119	1.004	2.215	0.986	0.929
47	2007	2.227	4.204	0.117	2.286	1.120	0.998	2.168	0.994	0.949
48	2008	2.351	4.261	0.121	2.474	1.120	0.983	2.272	0.992	0.997
49	2009	2.429	4.497	0.131	2.488	1.121	1.024	2.226	0.999	0.974
50	2010	2.503	4.236	0.133	2.597	1.122	1.009	2.302	1.002	0.996
51	2011	2.695	4.099	0.143	2.691	1.123	1.012	2.355	1.003	1.004
52	2012	2.855	4.345	0.148	2.704	1.123	1.022	2.323	1.005	1.009
53	2013	2.941	4.475	0.146	2.582	1.124	0.992	2.244	1.000	1.032
54	2014	2.908	4.754	0.137	2.495	1.125	1.008	2.207	1.000	0.996
55	2015	3.045	5.009	0.140	2.560	1.126	1.014	2.239	1.000	1.002
56	2016	3.089	5.166	0.140	2.522	1.126	1.012	2.193	1.006	1.002
57	2017	3.336	5.358	0.149	2.683	1.127	0.995	2.281	1.013	1.036
58	2018	3.404	5.612	0.149	2.625	1.128	1.016	2.231	1.008	1.019
59	2019	3.585	6.140	0.155	2.646	1.129	1.003	2.221	1.006	1.046
60	2020	3.711	6.878	0.167	2.633	1.130	0.995	2.181	1.013	1.061
61	2021	3.718	6.620	0.159	2.670	1.151	0.996	2.220	1.008	1.041

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

The UK

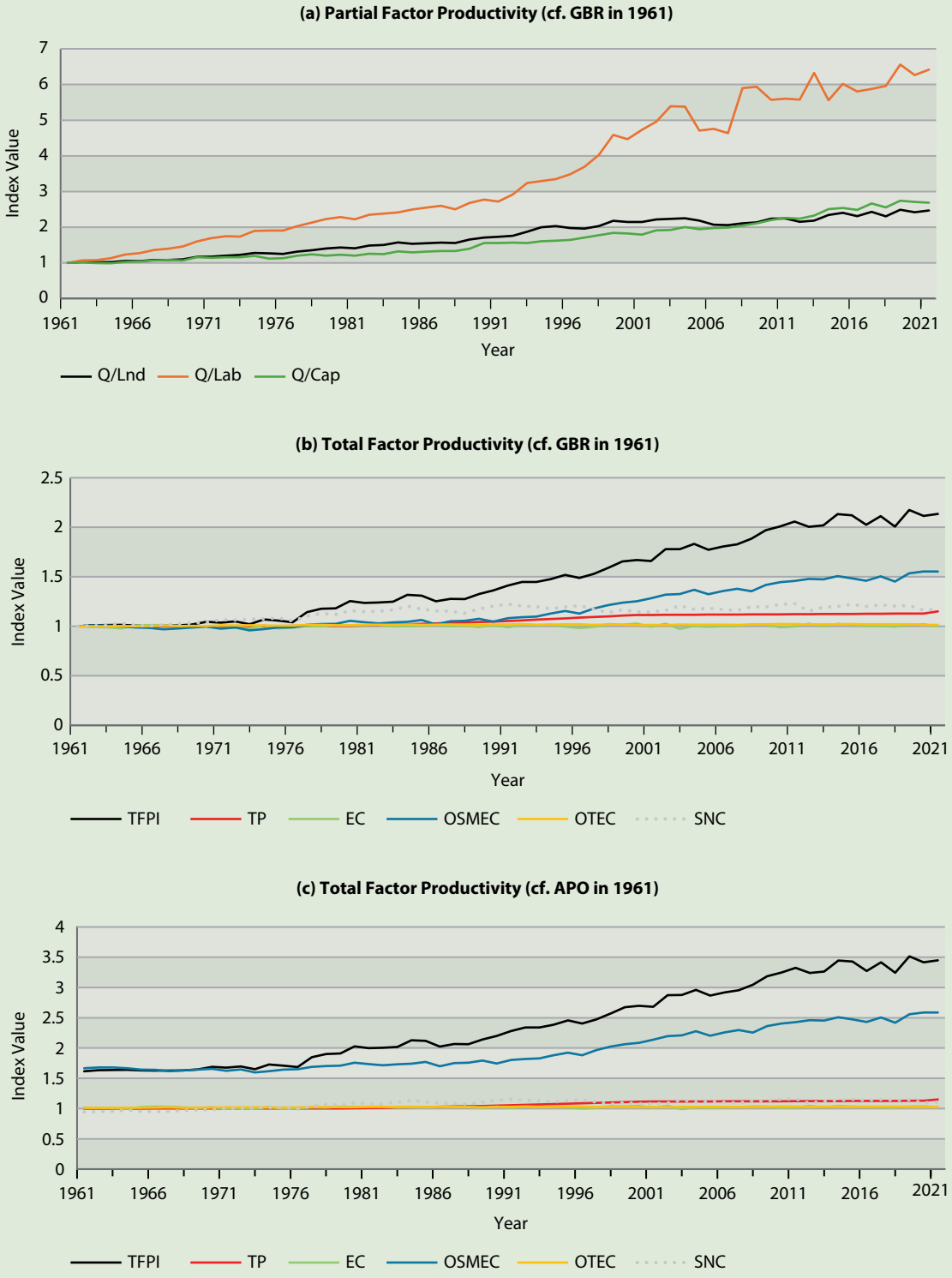
In 2019, UK's agriculture sector employed 1.4% (0.6%) of the male (female) labor force and contributed 0.6% to the country's GDP (FAO, 2025a, 2025b). Most of the cropping activity is concentrated in East Anglia, while livestock activity is concentrated in the Southwest. The average age of UK farmers is close to 60, as low farm incomes and high land prices have discouraged younger generations from joining the industry. Figure 28 reports the estimated changes in agricultural productivity in the UK from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 32. Figure 28(a) indicates that land and labor productivity increased over the sample period; in 2021, the output per unit of land (labor) was 2.470 times (6.418) higher than that in 1961. Capital productivity also increased over the sample period; in 2021, the output per unit of capital was 2.688 higher than that in 1961. Figure 28(b) indicates that the TFP in UK agriculture was 2.134 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 1.001 \times 1.151 \times 1.553 \times 1.016 \times 1.174 \\ &= 2.134. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had no impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a 55.3% increase in TFP, (iv) changes in technical efficiency (OTEC) had a small impact of 1.6% on TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 17.4% increase in measured TFP.

FIGURE 28

PRODUCTIVITY CHANGE IN THE UK



Source: Authors' illustration.

TABLE 32

PRODUCTIVITY CHANGE IN THE UK

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.029	1.072	1.014	1.011	1.000	0.993	1.009	1.000	1.008
3	1963	1.020	1.076	0.993	1.012	1.001	0.992	1.009	0.999	1.011
4	1964	1.026	1.135	0.990	1.014	1.001	0.978	1.001	1.003	1.031
5	1965	1.058	1.236	1.029	1.010	1.001	1.009	0.988	1.001	1.011
6	1966	1.050	1.273	1.039	1.006	1.002	1.013	0.985	1.004	1.003
7	1967	1.082	1.360	1.074	1.006	1.002	1.013	0.971	1.007	1.015
8	1968	1.084	1.400	1.085	1.009	1.002	1.002	0.979	1.002	1.024
9	1969	1.098	1.461	1.069	1.020	1.002	0.992	0.988	1.004	1.034
10	1970	1.169	1.601	1.160	1.045	1.003	1.004	0.996	1.004	1.039
11	1971	1.178	1.695	1.146	1.037	1.003	0.981	0.976	1.011	1.069
12	1972	1.206	1.750	1.158	1.049	1.003	0.986	0.989	1.008	1.063
13	1973	1.224	1.738	1.158	1.022	1.003	0.979	0.959	1.011	1.073
14	1974	1.282	1.898	1.198	1.070	1.004	1.009	0.973	1.010	1.076
15	1975	1.270	1.909	1.119	1.057	1.004	0.978	0.988	1.006	1.084
16	1976	1.252	1.906	1.133	1.042	1.004	0.987	0.991	1.008	1.053
17	1977	1.318	2.031	1.204	1.143	1.004	1.003	1.014	1.015	1.103
18	1978	1.356	2.134	1.240	1.177	1.004	0.998	1.023	1.015	1.131
19	1979	1.403	2.232	1.202	1.182	1.005	1.012	1.026	1.011	1.120
20	1980	1.433	2.285	1.231	1.255	1.005	1.010	1.055	1.012	1.158
21	1981	1.411	2.222	1.202	1.237	1.009	1.011	1.041	1.017	1.146
22	1982	1.489	2.351	1.257	1.240	1.013	1.015	1.030	1.017	1.151
23	1983	1.505	2.383	1.247	1.249	1.017	0.998	1.040	1.015	1.165
24	1984	1.575	2.417	1.323	1.318	1.022	1.004	1.046	1.020	1.205
25	1985	1.537	2.498	1.298	1.310	1.026	1.006	1.064	1.015	1.174
26	1986	1.554	2.554	1.316	1.253	1.030	1.015	1.020	1.016	1.157
27	1987	1.569	2.602	1.333	1.278	1.034	1.001	1.051	1.019	1.153
28	1988	1.561	2.503	1.335	1.276	1.039	1.010	1.056	1.016	1.134
29	1989	1.654	2.685	1.399	1.325	1.043	0.992	1.077	1.012	1.175
30	1990	1.708	2.778	1.558	1.362	1.047	1.013	1.047	1.018	1.203
31	1991	1.733	2.720	1.557	1.411	1.054	0.991	1.082	1.019	1.224
32	1992	1.762	2.917	1.567	1.449	1.061	1.015	1.093	1.023	1.204
33	1993	1.877	3.240	1.555	1.447	1.067	1.012	1.099	1.018	1.199
34	1994	2.000	3.292	1.606	1.476	1.074	1.017	1.129	1.017	1.177
35	1995	2.031	3.349	1.623	1.520	1.081	0.997	1.155	1.020	1.196
36	1996	1.979	3.484	1.643	1.489	1.087	0.983	1.130	1.020	1.208
37	1997	1.960	3.693	1.713	1.529	1.094	0.994	1.180	1.016	1.173
38	1998	2.035	4.027	1.775	1.591	1.101	1.023	1.215	1.020	1.140
39	1999	2.183	4.588	1.844	1.655	1.108	1.017	1.238	1.017	1.167
40	2000	2.148	4.466	1.823	1.669	1.115	1.028	1.253	1.013	1.146
41	2001	2.147	4.728	1.793	1.659	1.116	0.995	1.284	1.016	1.145
42	2002	2.219	4.959	1.914	1.779	1.116	1.028	1.320	1.013	1.160
43	2003	2.237	5.392	1.923	1.780	1.117	0.974	1.327	1.019	1.210

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	2.251	5.382	2.006	1.833	1.118	1.005	1.368	1.017	1.172
45	2005	2.185	4.709	1.947	1.774	1.118	0.995	1.324	1.017	1.184
46	2006	2.069	4.755	1.977	1.805	1.119	1.001	1.356	1.017	1.169
47	2007	2.062	4.637	1.988	1.828	1.120	1.004	1.379	1.016	1.160
48	2008	2.111	5.899	2.050	1.885	1.120	1.019	1.354	1.019	1.197
49	2009	2.138	5.939	2.107	1.971	1.121	1.015	1.418	1.022	1.195
50	2010	2.238	5.574	2.201	2.009	1.122	0.991	1.445	1.024	1.221
51	2011	2.247	5.606	2.265	2.058	1.123	1.000	1.458	1.023	1.230
52	2012	2.153	5.576	2.242	2.005	1.123	1.027	1.478	1.019	1.153
53	2013	2.185	6.322	2.325	2.019	1.124	1.000	1.474	1.020	1.194
54	2014	2.344	5.561	2.507	2.133	1.125	1.025	1.508	1.021	1.203
55	2015	2.403	6.017	2.539	2.121	1.126	1.016	1.485	1.022	1.222
56	2016	2.312	5.804	2.486	2.024	1.126	1.004	1.460	1.021	1.201
57	2017	2.429	5.878	2.667	2.113	1.127	1.003	1.505	1.020	1.217
58	2018	2.308	5.957	2.555	2.007	1.128	0.997	1.451	1.021	1.204
59	2019	2.491	6.561	2.744	2.175	1.129	1.015	1.536	1.021	1.211
60	2020	2.419	6.263	2.710	2.114	1.130	1.020	1.554	1.015	1.163
61	2021	2.470	6.418	2.688	2.134	1.151	1.001	1.553	1.016	1.174

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

The USA

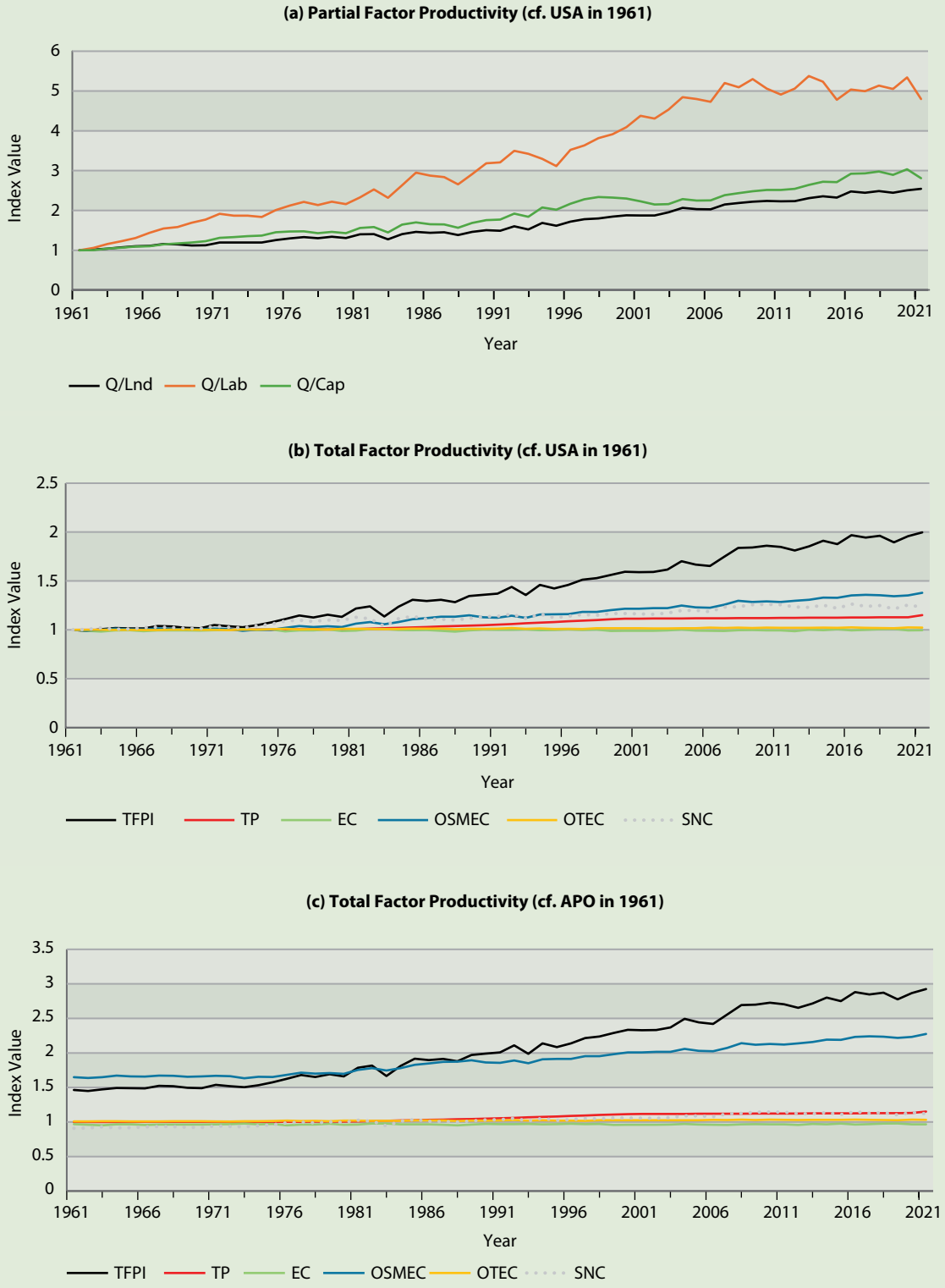
Agriculture is an important industry in the USA. In 2021, it employed 2.2% (1.0%) of the male (female) labor force and contributed 0.8% to the country's GDP (FAO, 2025a, 2025b). Most agricultural activity is concentrated in the Great Plains (in the central region) and the Corn Belt (around the Great Lakes). Major crops include corn, soybeans, wheat, potatoes, and sugar beets. Figure 29 reports the estimated changes in agricultural productivity in the USA from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 33. Figure 29(a) indicates that land and labor productivity increased over the sample period; in 2021, the output per unit of land (labor) was 2.544 (4.801) times higher than that in 1961. Capital productivity also increased over the sample period; in 2021, the output per unit of capital was 2.812 times higher than that in 1961. Figure 29(b) indicates that the TFP in US agriculture was 99.7% higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.998 \times 1.151 \times 1.379 \times 1.023 \times 1.233 \\ &= 1.997. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a negligible impact on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) led to a 37.9% increase in TFP, (iv) higher technical efficiency (OTEC) led to a 2.3% increase in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 23.3% increase in measured TFP.

FIGURE 29

PRODUCTIVITY CHANGE IN THE USA



Source: Authors' illustration.

TABLE 33

PRODUCTIVITY CHANGE IN THE USA

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.016	1.058	1.003	0.990	1.000	0.990	0.993	1.001	1.005
3	1963	1.043	1.159	1.040	1.006	1.001	0.983	1.001	1.001	1.021
4	1964	1.072	1.230	1.066	1.019	1.001	0.995	1.014	1.001	1.008
5	1965	1.100	1.309	1.091	1.016	1.001	0.997	1.007	1.001	1.011
6	1966	1.111	1.438	1.101	1.016	1.002	0.987	1.005	0.999	1.023
7	1967	1.158	1.548	1.146	1.039	1.002	0.994	1.014	1.000	1.029
8	1968	1.147	1.585	1.173	1.036	1.002	0.995	1.012	1.002	1.025
9	1969	1.119	1.691	1.196	1.022	1.002	0.995	1.004	1.003	1.018
10	1970	1.124	1.769	1.226	1.017	1.003	0.993	1.006	1.001	1.013
11	1971	1.195	1.915	1.311	1.050	1.003	0.996	1.013	1.000	1.038
12	1972	1.198	1.870	1.332	1.037	1.003	1.000	1.009	0.998	1.027
13	1973	1.195	1.871	1.352	1.026	1.003	1.008	0.990	1.003	1.021
14	1974	1.195	1.838	1.366	1.047	1.004	0.996	1.003	1.003	1.042
15	1975	1.257	2.011	1.451	1.075	1.004	1.004	1.001	1.006	1.058
16	1976	1.298	2.122	1.472	1.110	1.004	0.984	1.021	1.010	1.090
17	1977	1.331	2.213	1.474	1.147	1.004	0.994	1.040	1.006	1.098
18	1978	1.304	2.134	1.427	1.127	1.004	0.995	1.030	1.007	1.086
19	1979	1.340	2.218	1.463	1.156	1.005	1.005	1.037	1.004	1.100
20	1980	1.308	2.162	1.432	1.134	1.005	0.990	1.028	1.011	1.096
21	1981	1.402	2.330	1.559	1.219	1.009	0.994	1.064	1.012	1.129
22	1982	1.405	2.530	1.584	1.240	1.013	1.009	1.080	1.008	1.115
23	1983	1.276	2.318	1.447	1.137	1.017	1.008	1.059	1.008	1.038
24	1984	1.408	2.634	1.643	1.237	1.022	0.998	1.080	1.008	1.115
25	1985	1.464	2.952	1.699	1.308	1.026	0.997	1.108	1.012	1.140
26	1986	1.438	2.874	1.653	1.295	1.030	0.998	1.120	1.013	1.111
27	1987	1.454	2.840	1.648	1.307	1.034	0.991	1.135	1.013	1.108
28	1988	1.381	2.657	1.565	1.283	1.039	0.982	1.135	1.006	1.100
29	1989	1.464	2.911	1.686	1.346	1.043	0.995	1.149	1.011	1.116
30	1990	1.502	3.186	1.756	1.359	1.047	1.002	1.129	1.010	1.135
31	1991	1.491	3.206	1.770	1.371	1.054	1.001	1.126	1.013	1.139
32	1992	1.604	3.499	1.922	1.440	1.061	1.000	1.146	1.020	1.161
33	1993	1.523	3.421	1.842	1.357	1.067	1.004	1.122	1.010	1.117
34	1994	1.687	3.295	2.073	1.461	1.074	0.996	1.156	1.016	1.162
35	1995	1.615	3.113	2.021	1.424	1.081	0.999	1.160	1.010	1.126
36	1996	1.719	3.522	2.167	1.461	1.087	1.004	1.161	1.012	1.139
37	1997	1.782	3.635	2.279	1.513	1.094	0.999	1.184	1.009	1.158
38	1998	1.798	3.816	2.335	1.529	1.101	1.003	1.184	1.017	1.150
39	1999	1.847	3.912	2.323	1.563	1.108	0.990	1.201	1.017	1.167
40	2000	1.879	4.091	2.300	1.595	1.115	0.990	1.217	1.018	1.167
41	2001	1.873	4.376	2.230	1.590	1.116	0.991	1.217	1.016	1.164
42	2002	1.874	4.310	2.148	1.591	1.116	0.990	1.223	1.016	1.159
43	2003	1.955	4.533	2.160	1.617	1.117	0.995	1.223	1.015	1.172

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	2.066	4.843	2.286	1.703	1.118	1.002	1.248	1.017	1.199
45	2005	2.031	4.797	2.250	1.668	1.118	0.993	1.231	1.017	1.199
46	2006	2.030	4.727	2.252	1.652	1.119	0.991	1.227	1.023	1.187
47	2007	2.149	5.201	2.386	1.746	1.120	0.989	1.257	1.018	1.233
48	2008	2.186	5.093	2.435	1.838	1.120	0.998	1.298	1.024	1.237
49	2009	2.218	5.298	2.480	1.843	1.121	1.000	1.285	1.019	1.256
50	2010	2.238	5.062	2.513	1.861	1.122	0.996	1.291	1.024	1.260
51	2011	2.227	4.909	2.516	1.847	1.123	0.996	1.286	1.022	1.258
52	2012	2.236	5.060	2.541	1.812	1.123	0.987	1.297	1.021	1.235
53	2013	2.308	5.376	2.641	1.854	1.124	1.002	1.309	1.022	1.231
54	2014	2.355	5.234	2.722	1.912	1.125	0.997	1.330	1.023	1.252
55	2015	2.324	4.779	2.712	1.877	1.126	1.008	1.327	1.021	1.221
56	2016	2.479	5.036	2.922	1.968	1.126	0.995	1.353	1.026	1.265
57	2017	2.446	4.993	2.932	1.944	1.127	1.001	1.359	1.022	1.241
58	2018	2.486	5.137	2.979	1.961	1.128	1.008	1.355	1.019	1.250
59	2019	2.445	5.051	2.894	1.895	1.129	1.010	1.345	1.017	1.215
60	2020	2.505	5.342	3.035	1.957	1.130	0.996	1.353	1.026	1.254
61	2021	2.544	4.801	2.812	1.997	1.151	0.998	1.379	1.023	1.233

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

Vietnam

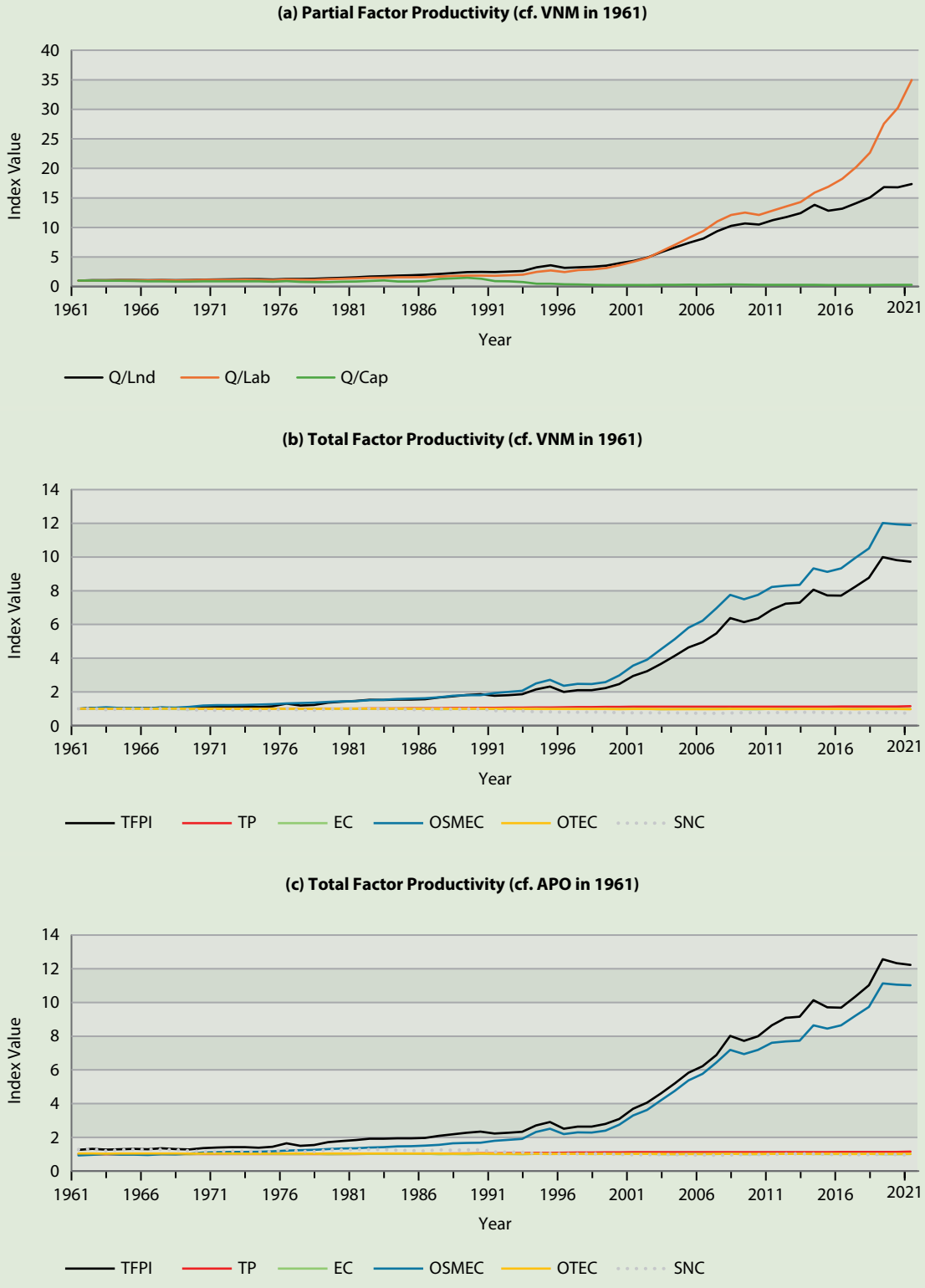
In 2021, the agriculture sector in Vietnam employed 27.7% (25.6%) of the male (female) labor force and contributed 11.8% to the country's GDP (FAO, 2025a, 2025b). Agricultural commodities account for approximately one third of all exports from Vietnam. It is the world's second largest exporter of rice. Figure 30 reports the estimated changes in agricultural productivity in Vietnam from 1961 to 2021. The index numbers used to construct these graphs are shown in Table 34. Figure 30(a) indicates that land and labor productivity increased over the sample period; in 2021, the output per unit of land (labor) was 17.350 (34.957) times higher than that in 1961. However, capital productivity fell; in 2021, the output per unit of capital was 29.8% of that in 1961. Figure 30(b) indicates that the TFP in Vietnamese agriculture was 9.730 times higher in 2021 than in 1961. The breakdown of this increase is as follows:

$$\begin{aligned} \text{TFPI} &= \text{EC} \times \text{TP} \times \text{OSMEC} \times \text{OTEC} \times \text{SNC} \\ &= 0.988 \times 1.151 \times 11.902 \times 0.975 \times 0.737 \\ &= 9.730. \end{aligned}$$

This decomposition indicates that, over the sample period, (i) changes in the production environment (EC) had a negative impact of 1.2% on TFP, (ii) TP led to a 15.1% increase in TFP, (iii) improvements in scale-mix efficiency (OSMEC) increased TFP by a factor of 11.902, (iv) lower technical efficiency (OTEC) led to a 2.5% fall in TFP, and (v) changes in omitted variables and other sources of statistical noise (SNC) accounted for a 26.3% fall in measured TFP.

FIGURE 30

PRODUCTIVITY CHANGE IN VIETNAM



Source: Authors' illustration.

TABLE 34

PRODUCTIVITY CHANGE IN VIETNAM

	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
1	1961	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1962	1.058	1.049	1.015	1.044	1.000	0.985	1.036	1.005	1.017
3	1963	1.072	1.054	0.989	1.012	1.001	0.999	1.081	0.996	0.940
4	1964	1.095	1.067	0.972	1.032	1.001	0.996	1.046	1.002	0.987
5	1965	1.106	1.068	0.946	1.044	1.001	0.987	1.053	1.004	1.000
6	1966	1.078	1.033	0.890	1.026	1.002	0.998	1.028	1.000	0.998
7	1967	1.115	1.073	0.901	1.069	1.002	0.986	1.077	1.001	1.004
8	1968	1.084	1.039	0.850	1.034	1.002	0.989	1.059	1.002	0.984
9	1969	1.112	1.059	0.846	1.021	1.002	0.978	1.112	0.993	0.943
10	1970	1.174	1.127	0.875	1.082	1.003	1.003	1.190	0.998	0.906
11	1971	1.205	1.134	0.880	1.107	1.003	1.005	1.213	0.999	0.905
12	1972	1.235	1.144	0.870	1.131	1.003	1.000	1.217	0.998	0.928
13	1973	1.251	1.153	0.879	1.124	1.003	0.993	1.226	0.996	0.925
14	1974	1.257	1.141	0.871	1.102	1.004	0.998	1.240	0.993	0.893
15	1975	1.210	1.090	0.833	1.149	1.004	1.002	1.263	0.997	0.907
16	1976	1.301	1.186	0.904	1.308	1.004	0.987	1.313	1.000	1.006
17	1977	1.285	1.167	0.786	1.194	1.004	0.980	1.332	0.997	0.913
18	1978	1.311	1.175	0.748	1.224	1.004	1.003	1.360	0.990	0.903
19	1979	1.413	1.264	0.764	1.363	1.005	0.980	1.407	1.000	0.985
20	1980	1.482	1.319	0.819	1.415	1.005	0.990	1.437	1.004	0.986
21	1981	1.579	1.387	0.866	1.458	1.009	0.993	1.455	1.003	0.997
22	1982	1.700	1.482	0.945	1.529	1.013	0.995	1.506	1.001	1.005
23	1983	1.766	1.517	1.028	1.521	1.017	0.992	1.528	0.999	0.988
24	1984	1.839	1.566	0.870	1.546	1.022	0.996	1.575	1.002	0.963
25	1985	1.910	1.578	0.843	1.542	1.026	0.993	1.596	0.998	0.950
26	1986	1.995	1.616	0.910	1.565	1.030	1.007	1.625	0.998	0.930
27	1987	2.124	1.688	1.304	1.663	1.034	0.977	1.683	0.998	0.980
28	1988	2.303	1.784	1.397	1.738	1.039	0.982	1.775	0.996	0.964
29	1989	2.438	1.856	1.482	1.810	1.043	0.980	1.798	0.999	0.987
30	1990	2.490	1.865	1.323	1.858	1.047	0.997	1.807	1.001	0.983
31	1991	2.459	1.816	0.915	1.766	1.054	0.983	1.934	0.995	0.886
32	1992	2.525	1.907	0.900	1.804	1.061	0.982	1.994	0.993	0.875
33	1993	2.639	2.000	0.771	1.855	1.067	0.979	2.061	0.990	0.870
34	1994	3.246	2.469	0.485	2.147	1.074	1.002	2.496	0.986	0.810
35	1995	3.598	2.712	0.482	2.314	1.081	0.990	2.710	0.980	0.815
36	1996	3.165	2.455	0.387	1.997	1.087	1.000	2.364	0.980	0.793
37	1997	3.264	2.793	0.342	2.098	1.094	0.992	2.473	0.983	0.795
38	1998	3.338	2.896	0.300	2.098	1.101	0.981	2.460	0.981	0.804
39	1999	3.529	3.118	0.277	2.223	1.108	1.002	2.581	0.981	0.791
40	2000	3.990	3.636	0.272	2.461	1.115	0.987	2.971	0.978	0.769
41	2001	4.361	4.237	0.266	2.937	1.116	1.002	3.553	0.982	0.753
42	2002	4.940	4.870	0.272	3.224	1.116	0.999	3.910	0.979	0.755
43	2003	5.854	5.993	0.293	3.658	1.117	0.978	4.526	0.976	0.758

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	Year	Q/Lnd	Q/Lab	Q/Cap	TFPI	TP	EC	OSMEC	OTEC	SNC
44	2004	6.670	7.129	0.307	4.134	1.118	0.979	5.132	0.970	0.759
45	2005	7.426	8.309	0.313	4.637	1.118	0.993	5.810	0.974	0.738
46	2006	8.132	9.397	0.308	4.945	1.119	0.987	6.224	0.973	0.739
47	2007	9.369	11.019	0.332	5.473	1.120	0.991	6.954	0.975	0.728
48	2008	10.287	12.103	0.340	6.374	1.120	1.007	7.759	0.981	0.742
49	2009	10.687	12.512	0.333	6.140	1.121	0.978	7.491	0.980	0.763
50	2010	10.507	12.120	0.298	6.361	1.122	0.978	7.757	0.979	0.763
51	2011	11.248	12.864	0.293	6.875	1.123	0.998	8.219	0.983	0.760
52	2012	11.771	13.591	0.290	7.230	1.123	0.998	8.304	0.977	0.795
53	2013	12.444	14.307	0.286	7.284	1.124	1.000	8.345	0.980	0.792
54	2014	13.832	15.888	0.295	8.067	1.125	0.982	9.329	0.983	0.796
55	2015	12.826	16.876	0.276	7.723	1.126	0.986	9.128	0.988	0.772
56	2016	13.191	18.222	0.272	7.710	1.126	0.989	9.332	0.982	0.755
57	2017	14.128	20.229	0.274	8.230	1.127	0.999	9.937	0.973	0.756
58	2018	15.082	22.675	0.274	8.769	1.128	0.992	10.513	0.981	0.760
59	2019	16.818	27.567	0.287	9.996	1.129	0.975	12.020	0.981	0.770
60	2020	16.808	30.230	0.292	9.813	1.130	0.979	11.945	0.979	0.758
61	2021	17.350	34.957	0.298	9.730	1.151	0.988	11.902	0.975	0.737

EC, environmental change; OSMEC, output-oriented scale-mix efficiency change; OTEC, output-oriented technical efficiency change; SNC, statistical noise change; TFPI, total factor productivity index; TP, technical progress.
Source: Authors' data.

MONITORING AGRICULTURAL PRODUCTIVITY CHANGE IN ASIA

This chapter discusses some of the general issues and challenges involved in monitoring agricultural productivity change. It also provides specific recommendations for improving agricultural productivity measurement and analysis in Asia.

Issues and Challenges

Monitoring agricultural productivity changes requires measuring output and input changes. The main challenge in measuring these changes (and, thus, productivity changes) lies in the collection of accurate data. Data must not only be accurate but also collected at a level that is useful for policy-making. Before collecting the data, analysts must be careful in defining the following:

1. *Level of analysis*. Productivity measurement is ultimately aimed at measuring the performance of specific decision-makers (e.g., farm managers or government ministers). Decision-makers at different levels (e.g., farm or sector level) make decisions about different variables (e.g., farm managers make decisions concerning farm-level inputs of seed and pesticides while government ministers make decisions about fertilizer subsidies and the building of dams). Arguably, the most useful data for monitoring and analyzing agricultural productivity change are farm-level data.

2. *Variables involved in agriculture*. Generally, variables involved in the agricultural production process can be classified based on whether they are chosen by managers. The variables that are chosen by managers can be further sub-divided into inputs and outputs. Those that are *never* chosen by managers should be viewed as environmental variables (e.g., rainfall). Monitoring agricultural productivity change requires data on outputs and inputs, while *analyzing* agricultural productivity change requires data on environmental variables and other variables that affect farmer decision-making (e.g., prices, government policy).

3. *Variables of interest*. Productivity is a measure of output volume (or quantity) divided by a measure of input volume. On the one hand, in the business literature, "productivity" is sometimes used to refer to measures of output value (e.g., revenue and value-added) divided by measures of input value (i.e., cost). On the other hand, in the productivity literature, "productivity" is often used to refer to a combination of TP and technical efficiency improvement (e.g., Färe et al., 1994). All these variables (i.e., revenue, value-added, cost, TP, and technical efficiency) are of interest to policymakers. However, except in restrictive special cases, most economists do not consider them as measures of productivity. Indeed, increases in some of these variables (e.g., revenue) may be associated with *decreases* in productivity. Monitoring productivity change must be preceded by a very clear definition of the term "productivity."

4. *Country-specific policy recommendations*. We did not conduct a historical analysis to see how specific policy changes in individual countries align with changes in their scale and mix efficiency. This is outside the scope of this report and would require expert knowledge of individual countries. However, in the last section of Chapter 4, we summarized the results for Asian countries, half of which are APO members; we concluded that, for Asian countries, TP led to a 15.1% increase in TFP, improvements in scale-mix efficiency (OSMEC) led to a 194.3% increase in TFP, while changes in the other components (EC and OTEC) had little or no impact on TFP. TP is a global phenomenon (and most likely driven by R&D in countries such as the USA), so APO members should focus on OSMEC. They should also identify any historical policy changes that may have been driving increases in scale and mix efficiency. We mention the relevant types of policies in point 3 of the following subsection.

Recommendations

In our previous APO report (see O'Donnell & Peyrache, 2020), we identified several problematic areas that required attention. In this report, we have the following recommendations for the APO:

1. Work with experienced statistical agencies (e.g., Economic Research Service of the USDA and the Australian Bureau of Agricultural and Resource Economics and Sciences) to develop survey questionnaires that can be used to collect farm-level data for agricultural productivity analysis. The first priority should be given to collecting volume (i.e., quantity) data on all variables that are physically involved in the production process (i.e., inputs, outputs, and characteristics of the production environment). The second priority should be given to collecting data on output and input prices (or values of inputs and outputs; prices can be obtained by dividing values by volumes). The third priority should be given to collecting data on technologies (i.e., the techniques that farmers use to transform inputs into outputs), the personal characteristics of farm managers (e.g., age, education, and gender), and any government initiatives that are likely to influence farmer decision-making (e.g., new regulations governing the use of pesticides).

2. Work with appropriate statistical agencies in APO-member economies to conduct a comprehensive farm-level survey in each economy on a regular basis (e.g., once every 3 years). Care should be taken to minimize both non-sampling and sampling errors. Non-sampling errors can be minimized by working with local producer groups and using a good questionnaire, well-trained interviewers, and an up-to-date sampling frame. Sampling errors can be reduced by increasing the sample size and using an appropriate sampling design (e.g., stratified random or cluster sampling).

3. Use primary and secondary data to measure and analyze measures of PFP and TFP *at the farm level*. The primary aims of the analysis should be to identify (a) the effects of changes in climate, public infrastructure, and other environmental variables on plot- and/or farm-level productivity; (b) the effects of research and development expenditure on the discovery of new commodity- and environment-specific production technologies (e.g., new techniques for producing almonds in a dry temperate climate); (c) the effects of government extension and training programs on the adoption and implementation of new technologies; (d) returns to scale and substitution in agricultural production and input use (e.g., increases in productivity associated with substituting capital for labor, or reductions in profits associated with producing commodities that have a relatively small environmental footprint); and (e) how commodity prices and/or government

policies may influence farmer output and/or input choices (e.g., the way fertilizer subsidies may have led to increased fertilizer use).

We re-iterate the importance of these points and the need to collect more accurate data. Ideally, as mentioned above, one should be able to access farm level data allowing for a more precise assessment of productivity levels. Although we were unable to address this point in the current report, as conducting country-specific surveys would require additional resources, the data used in this report represent a significant improvement over the data collected in the previous report. The data are more accurate and precise in the current report, and the number of countries has been substantially increased. Moreover, we were able to extend the analysis by an additional 6 years, with the sample period covering all years from 1961 to 2021.

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ABBREVIATIONS

APO	Asian Productivity Organization
CRS	Constant returns to scale
DEA	Data envelopment analysis
EC	Environmental change
ETC	Environment and technical change
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GY	Geometric Young
HM	Hicks-Moorsteen index
ILO	International Labour Organization
ISO	International Organization for Standardization
LP	Linear program
ML	Maximum likelihood
ODF	Output distance function
OETSMEC	Output-oriented environment, technology, and scale-mix efficiency change
OECD	Organisation for Economic Co-operation and Development
OSME	Output-oriented scale-mix efficiency
OSMEC	Output-oriented scale-mix efficiency change
OTE	Output-oriented technical efficiency
OTEC	Output-oriented technical efficiency change
PDF	Probability density function
PFP	Partial factor productivity
SFA	Stochastic frontier analysis
SFM	Stochastic frontier model
SNC	Statistical noise change
TC	Technical change
TFP	Total factor productivity
TFPI	Total factor productivity index
TP	Technical progress
TSME	Technical and scale-mix efficiency
TSMEC	Technical and scale-mix efficiency change
USDA	United States Department of Agriculture
WB	World Bank

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