SIX DECADES OF TOTAL FACTOR PRODUCTIVITY CHANGE AND SOURCES OF GROWTH IN BANGLADESH AGRICULTURE[1] (1948–2008)

Sanzidur Rahman
School of Geography, Earth and Environmental Sciences, University of Plymouth, Plymouth, PL4 8AA, United Kingdom

Ruhul Salim
School of Economics and Finance, Curtin Business School, Curtin University, Perth, WA 6845, Australia

Address for Correspondence

Dr Sanzidur Rahman
Associate Professor in Rural Development
School of Geography, Earth and Environmental Sciences
University of Plymouth
Drake Circus
Plymouth, PL4 8AA
England, UK
Phone: +44-1752-585911
Fax: +44-1752-585998
E-mail: srahman@plymouth.ac.uk

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Sanzidur Rahman and Ruhul Salim[2]

ABSTRACT

This paper applies the Färe-Primont index to calculate total factor productivity (TFP) indices for agriculture in 17 regions of Bangladesh covering a 61 year period (1948-2008). It decomposes the TFP index into six finer components (technical change, technical, scale and mix efficiency changes, residual scale and residual mix efficiency changes). Results reveal that TFP grew at an average rate of 0.57% p.a. led by the Chittagong, Rajshahi, Rangpur, Dinajpur and Noakhali regions. TFP growth is largely powered by technological progress estimated at 0.74% p.a. Technical efficiency improvement is negligible (0.01% p.a.) due to stagnant efficiency in most of the regions. Decline in scale efficiency is also negligible (0.01% p.a.) but the decline in mix efficiency is high at 0.19% p.a. Decomposition of the components of TFP changes into finer measures of efficiency corrects the existing literature's blame of a decline in technical efficiency as the main cause of poor TFP growth in Bangladesh. Among the sources, farm size, R&D investment, extension expenditure, and crop specialization positively influenced TFP growth whereas the literacy rate had a negative influence on growth. Policy implications include encouraging investment in R&D and extension, land reform measures to increase average farm size, promotion of Green Revolution technology, and crop diversification.

JEL Classification: O4, Q1.

Keywords: Färe-Primont TFP index, technical change, technical, scale and mix efficiency

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[2] Sanzidur Rahman is the contact author (srahman@plymouth.ac.uk) and is with the School of Geography, Earth and Environmental Sciences, University of Plymouth, Plymouth, PL4 8AA, United Kingdom. Ruhul Salim is at the School of Economics and Finance, Curtin Business School, Curtin University, Perth, Australia. Creation of the required database for this project was generously supported by the British Academy Small Research Grant 2009. The authors also gratefully acknowledge contribution of Dr. M.A. Hamid who has compiled most of the required data under the research grant scheme. The paper was presented at an invited seminar at the School of Economics and Finance, Curtin Business School, Perth Australia on August 09, 2012. The authors gratefully acknowledge comments and suggestions of three referees and the chief editor that has substantially improved the paper. All caveats remain with the authors.

changes, Bangladesh.

1. Introduction

Agriculture is the major source of livelihood in Bangladesh, accounting for 23.5% of national income and employing 62% of the labour force (MoA, 2008). The dominant sector is field crop agriculture, accounting for more than 60% of agricultural value added. Among the field crops, rice is the major staple crop, occupying 70% of the gross cropped area (BBS, 2009). However, agricultural production falls short of demand resulting in a chronic food deficit. Concerned with the chronic food shortage, the government of Bangladesh embarked on a policy of rapid technological progress in agriculture involving the diffusion of a rice-based "Green Revolution" (GR) technology package involving high yielding varieties (HYV) of rice, chemical fertilizers, pesticides and irrigation intervention. As a result, agricultural production recorded a substantial increase over the past few decades, jumping from 1,500 metric tons in 1968 to 26,530 thousand metric tons in 2006 (Rahman, 2010; MoA, 2008). Use of modern inputs also increased dramatically. For example, fertilizer consumption increased from 0.18 million tons of nutrients in 1973 to 1.70 million tons of nutrients in 2006. Pesticide use increased from only 3.13 thousand tons of active ingredients in 1977 to 17.39 thousand tons in 2002. And the proportion of irrigated area in gross cropped area (GCA) increased from only 11.0% in 1973 to 37.5% in 2006 (Rahman, 2010).

However, recent trends have been less encouraging. First, there is a controversy about the performance of HYV rice, which is the main engine of production growth. The yield of HYV rice actually fell at a rate of 1.0% p.a. during 1960-1985 and then reversed and grew at a rate of 1.4% p.a. during 1986-2006 (Rahman, 2010). Second, the adoption of GR technology seems to have stagnated. The observed increase in production at an annual rate of 2.3% since early 1970s is largely due to conversion from traditional rice to HYVs rather than any increase in yields of HYVs (Baffes and Gautam, 2001). The use of modern inputs in

Bangladesh is less than the global average; however, the increasing use of more modern inputs is not a viable option in the long run either due to limited availability of crop-land or to the diminishing nature of input-driven growth. It follows that the strategy for increasing output needs to rely on progress in technology and efficiency in the coming decades if agricultural supply is to keep up with growing demand for food (Rahman, 2007).

Improvements in agricultural productivity are a fundamental pre-condition for sustainable economic development, since agricultural productivity increases allow resources such as labour and capital to be diverted to expand the non-agricultural sector of the economy (O'Donnell, 2010). Total Factor Productivity (TFP) indices capture the effect of improvements in technology in the form of research and development as well as investments in infrastructure such as irrigation, roads and electricity (Mukherjee and Kuroda, 2003). Higher TFP is desirable as it not only implies higher output from application of technology and better utilization of resources, but also leads to a reduction in poverty in rural areas (Fan *et al*., 2000), a major policy objective of the Bangladeshi government.

Studies on TFP growth in Bangladesh crop agriculture are limited, with mixed results and all are outdated. The latest database used for TFP analysis covered up to 1992 only (e.g., Coelli *et al*., 2003; Rahman, 2007) whereas performance of the agricultural sector in Bangladesh is believed to have picked up following substantial reforms initiated during the 1990s. These reforms were mainly aimed at reducing subsidies, reorganizing the public food distribution system and realigning market incentives, all of which are assumed to contribute to productivity growth in agriculture. The previous estimates of TFP growth rates of Bangladesh agriculture varied from 0.3% p.a. for the period 1948-81 (Pray and Ahmed, 1991) to 0.9% p.a. for the period 1973-89 (Dey and Evenson, 1991), between -0.2% p.a. for the period 1961–1992 (Coelli *et al*., 2003) and 0.9% p.a. for the same period (Rahman, 2007). The contrast between the results of Coelli *et al*., (2003) and Rahman (2007) using the same dataset is largely due to the approach used. The former used a stochastic production frontier approach to derive the Malmquist productivity index while the latter applied the non-parametric approach to derive a sequential Malmquist productivity index. It is well known that DEA is a deterministic technique that does not take into account the stochasticity of the data and therefore provides results contaminated with noise. Also, for the developing nations, markets for major inputs, such as land and labour, are not sufficiently developed to provide any meaningful prices (Thirtle *et al*., 2003). Therefore, the Tornqvist-Theil index used by Pray and Ahmed (1981) and Dey and Evenson (1991) may have biased the results because of the need for price information. Although the Malmquist index used by Rahman (2007) and Coelli *et al*., (2003) used shadow prices, the period covered remained outdated. Despite the widespread application of the Malmquist productivity index of Caves, Christensen and Diewert (1982) popularised by Färe *et al* (1994) and Ray and Desli (1997) in the literature, many authors, such as Grifell-Tatje and Lovell (1995), Wheelock and Wilson (1999), and more recently O'Donnell (2010, 2012, 2012a, 2012b) argue that apart from special cases, such as constant returns to scale and inverse homotheticity, the Malmquist index is a biased measure of TFP change. O'Donnell (2012b) first proposed the Färe-Primont productivity index which, although requires specification of the production technology (in the form of output and input distance functions), is free from restrictive assumptions about the nature of the production technology, firm's optimizing behaviour, structure of markets, returns to scale and/or price information. Moreover, the Färe-Primont productivity index satisfies all other regularity conditions of index numbers such as multiplicative completeness and transitivity (O'Donnell, 2012b).

We apply a programming approach to the analysis of agricultural productivity and associated efficiency measures in all the 17 regions of Bangladesh covering a 61 year period (1948–2008) and examine the sources of TFP growth and its components. Our contribution to the existing literature is three-fold. First, the Färe-Primont index is used to compute the TFP indices that are economically ideal in the sense that it satisfies all economically relevant axioms and tests of index number theory including transitivity and identity tests and is a reliable measure for comparing multi-temporal (many periods) and/or multi-lateral (many firms) indices of TFP and efficiency (O'Donnell, 2012). Also, the Färe-Primont index does not require any restrictive assumptions about the nature of the production technology, price information and assumptions regarding the behaviour of the firms or the level of competition in input or output markets (O' Donnell, 2012a, 2012b). Second, the TFP index is decomposed into six finer measures instead of two or three (i.e., technical change, technical efficiency change and scale efficiency change) commonly presented in the literature. These are: technical change, technical efficiency change, scale efficiency change, mix efficiency change, residual mix efficiency change, and residual scale efficiency change. Generally, different policies have different effects on various components of productivity change and this decomposition analysis allows the differential impact of policies to be identified. For example, research and development (R&D) is likely to affect farms' technical progress while education and training programs help move farms towards the 'best practice' frontier, while taxes and subsidies affect scale efficiencies. Third, this study covers all the previous study periods (i.e., 1948-1981, 1973-1989, and 1961-1992) and extends the data to 2008, thus capturing outcomes of the various agricultural sector reforms undertaken since early 1990s on TFP growth, and hence providing a more complete picture of the sector's long-term performance as well as identifying the factors contributing to TFP growth and its components.

The paper is organized as follows. Section 2 discusses the methodology employed to construct the TFP indices and associated efficiency decompositions. Section 3 describes the data. Section 4 reports and interprets efficiency and TFP results. Section 5 presents the results of the determinants of TFP growth and its components. Finally, Section 6 summarizes and concludes.

2. Methodology[3]

A programming approach is adopted, applying index number theory, which is a measure of change in a variable or a group of variables, over time and space. Specifically, the Färe-Primont index of TFP change is computed for each of the 17 agricultural regions of Bangladesh and productivity changes are decomposed into the six components mentioned above. This index number approach is developed using the aggregate-quantity framework which does not rely on the availability of price data and does not require any assumptions concerning either the degree of competition in the product markets or the optimizing behaviour of firms (O'Donnell, 2012, 2012b). The analytical procedure involves the Data Envelopment Analysis (DEA) linear program (LP) to estimate the production technology and associated productivity and efficiency levels: (a) technical change (measuring movements in the production frontier); (b) technical efficiency change (movements towards or away from the frontier; (c) scale efficiency change (movements around the frontier surface to capture economies of scale); and (d) mix efficiency change (movements around the frontier to capture economies of scope) (O'Donnell, 2010, 2011a, 2012b).

2.1 The Färe-Primont index of Total Factor Productivity

Following Jorgenson and Grilliches (1967) and Good *et al*. (1997), in the case of a multi-input multi-output farm, O'Donnell (2010) defines total factor productivity (TFP) growth as

$$TFP_{it} = \frac{Q_{it}}{X_{it}} \qquad (1)$$

[3] The methodology for this study is based on the analytical framework and the corresponding software program (DPIN-V3) developed by O'Donnell (2010, 2011). Therefore, most of the descriptions in this section are largely adapted from O'Donnell (2010, 2011a; 2012, 2012a, 2012b).

where $Q_{it} = Q(q_{it})$ is an aggregate output, $X_{it} = X(x_{it})$ is an aggregate input, and $Q(.)$ and $X(.)$ are non-negative, non-decreasing and linearly homogeneous aggregator functions. The associated index number that measures TFP of firm *i* in period *t* relative to TFP of firm *h* in period *s* is (O'Donnell, 2011, 2011a):

$$TFP_{hs,it} = \frac{TFP_{it}}{TFP_{hs}} = \frac{Q_{it} / X_{it}}{Q_{hs} / X_{hs}} = \frac{Q_{hs,it}}{X_{hs,it}} \qquad (2)$$

where $Q_{hs,it} = Q_{it} / Q_{hs}$ is an output quantity index and $X_{hs,it} = X_{it} / X_{hs}$ is an input quantity index. Thus TFP change can be expressed as a measure of output change divided by a measure of input change.

The Färe-Primont aggregator function that is non-negative, non-decreasing and linearly homogenous is used (O'Donnell, 2011a):

$$Q(q) = D_O(x_0, q, t_0) \qquad (3)$$

$$X(x) = D_I(x, q_0, t_0) \qquad (4)$$

where *q* and *x* are vectors of input and output quantities and $D_O(.)$ and $D_I(.)$ are the output and input distance functions. The Färe-Primont TFP index is given by (O'Donnell, 2011a):

$$TFP_{hs,it} = \frac{D_O(x_0, q_{it}, t_0)}{D_O(x_0, q_{hs}, t_0)} \frac{D_I(x_{hs}, q_0, t_0)}{D_I(x_{it}, q_0, t_0)} \qquad (5)$$

Using DEA, one can calculate the distance functions and thus generate the Färe-Primont TFP index. O'Donnell (2010, 2011) develops a DEA methodology for computing and decomposing the Färe-Primont TFP index (for a detailed explanation of the linear programmes see O'Donnell, 2011; 2011a).

2.2 Measures of efficiency

The following finer measures of efficiency change are computed by decomposing TFP changes. These efficiency measures are defined and explained with reference to two production frontiers: a mix-restricted production frontier (when the mixes of outputs or inputs are held fixed) and an unrestricted production frontier (when both input and output mixes are allowed to vary), where each point refers to a combination of aggregate input and output (Figure 1, adapted from O'Donnell, 2012a):

Input-oriented technical efficiency $ITE_{it} = \dfrac{Q_{it} / X_{it}}{Q_{it} / \bar{X}_{it}} = \dfrac{\bar{X}_{it}}{X_{it}} = D_I(x_{it}, q_{it}, t)^{-1} \leq 1$ (6)

Input-oriented scale efficiency $ISE_{it} = \dfrac{Q_{it} / \bar{X}_{it}}{\tilde{Q}_{it} / \tilde{X}_{it}} \leq 1$ (7)

Input-oriented mix efficiency $IME_{it} = \dfrac{Q_{it} / \bar{X}_{it}}{Q_{it} / \hat{X}_{it}} = \dfrac{\hat{X}_{it}}{\bar{X}_{it}} \leq 1$ (8)

Residual input-oriented scale efficiency $RISE_{it} = \dfrac{Q_{it} / \hat{X}_{it}}{Q^*_{it} / X^*_{it}} \leq 1$ (9)

Residual mix efficiency $RME_{it} = \dfrac{Q_{it} / \tilde{X}_{it}}{Q^*_{it} / X^*_{it}} \leq 1$ (10)

where $TFP^*_t = Q^*_{it} / X^*_{it}$ denotes maximum TFP that is possible using the technology available in period *t*; $\bar{X}_{it} = X_{it} D_I(x_{it}, q_{it}, t)^{-1}$ is the minimum aggregate input possible when using a scalar multiple of x_{it} to produce q_{it}; $\tilde{Q}_{it}$ and $\tilde{X}_{it}$ are the (output-mix and input-mix preserving) aggregate output and input quantities at the point of mix-invariant optimal scale (MIOS), which refers to a point where a ray through the origin is tangent to the mix-restricted production frontier; $\hat{Q}_{it}$ and $\hat{X}_{it}$ are the aggregate output and input obtained when TFP is maximized subject to the constraint that the output and input vectors are scalar multiples of q_{it} and x_{it}, respectively (O'Donnell, 2012a).

Eq. (6) presents the most common measure of the input-oriented technical efficiency, that is, the minimum aggregate input possible to produce a given level of aggregate output (slope OA/slope OB). The scale efficiency in Eq. (7) is the commonly used measure which shows efficiency derived due to economies or diseconomies of scale (i.e., by varying operation size) and is expressed here as the ratio of TFP at a technically efficient point to TFP at an associated point of MIOS (slope OB/slope OD). Mix efficiency in Eq (8) is a measure of the potential change in productivity when restrictions on input and output mix are relaxed. Mix efficiency depends on the economies or diseconomies of scope in input use. The pure mix efficiency is closely related to the familiar concept of cost-allocative efficiency. This is the ratio of TFP at a technically efficiency point on the mix-restricted frontier to TFP at a point on the unrestricted frontier (slope OB/slope OU). Residual scale efficiency in Eq. (9) is the ratio of TFP at a technically- and mix-efficient point to TFP at a point of maximum productivity, which is a scale effect (slope OU/slope OE). However, the term residual is used here to reflect the fact that although all points on the unrestricted frontier are mix-efficient, each has different input and output mixes. Finally, the residual mix efficiency is the ratio of TFP at a point of MIOS to TFP at a point of maximum productivity. This involves movement from an optimal point on the mix-restricted frontier to the optimal point on the unrestricted frontier, which is a mix-effect (slope OD/slope OE). The term residual is used because such movement also involves a possible change in scale (for full details, O'Donnell, 2012a).

[Insert Figure 1 here]

2.3 The components of TFP change

The TFP indices expressed in terms of aggregate quantities as in Eq. (2) are multiplicatively complete. O'Donnell (2011a) presents the decomposition of TFP changes in the aggregate quantity space as follows:

$$TFP_{hs,it} = \left(\frac{TFP_t^*}{TFP_s^*}\right)\left(\frac{ITE_{hs}}{ITE_{hs}}\right)\left(\frac{ISE_{hs}}{ISE_{hs}}\right)\left(\frac{RME_{hs}}{RME_{hs}}\right) = \left(\frac{TFP_t^*}{TFP_s^*}\right)\left(\frac{ITE_{hs}}{ITE_{hs}}\right)\left(\frac{IME_{hs}}{IME_{hs}}\right)\left(\frac{RISE_{hs}}{RISE_{hs}}\right) \qquad (11)$$

The first term in parenthesis of the right hand side of Eq. (11) is a natural measure of technical change that captures the difference between the maximum TFP possible using the unrestricted technology in period *t* and the maximum TFP using the unrestricted technology in period s. A farm experiences technical progress or regress as the value of this indicator is greater or less than unity. The other ratios are efficiency changes defined in Eqs. (6) to (10). These terms can take a value greater or less than unity corresponding to the status of being more efficient or less efficient relative to reference technologies in respective periods t and s. The value of unity of all of these components means that there is no change in the efficiency scores.

2.4 Estimation using DEA

The main assumption underpinning use of DEA is that the (local) input distance function representing the technology available in period t takes the form (O'Donnell, 2011):

$$D_I(x_{it}, q_{it}, t) = (x_{it}^{'}\eta)/(q_{it}^{'}\phi - \delta) \qquad (12)$$

The input-oriented problem involves selecting values of the unknown parameters in Equation (12) in order to maximize technical efficiency: $ITE_{it} = D_I(x_{it}, q_{it}, t)^{-1}$. The resulting LP is:

$$D_I(x_{it}, q_{it}, t)^{-1} = ITE_{it} = \max_{\phi,\delta,\eta} \{q_{it}^{'}\phi - \delta : Q'\phi \leq \delta t + X'\beta; x_{it}^{'}\eta = 1; \phi \geq 0; \eta \geq 0\} \qquad (13)$$

where $\boldsymbol{Q}$ is a J x M_t matrix of observed outputs, $\boldsymbol{X}$ is a K x M_t matrix of observed inputs, t is an M_t *x 1* unit vector, and M_t denotes the number of observations used to estimate the frontier in period t (for details, see O'Donnell, 2011). The DPIN-V3 software programme uses a variant of this LP to compute various indices of productivity and efficiency measures.

Specifically, to compute the Färe-Primont aggregates, DPIN-V3 first solves the following LP (O'Donnell, 2011):

$$D_I(x_0, q_0, t_0)^{-1} = ITE_0 = \max_{\phi,\delta,\eta} \{q_0^{'}\phi - \delta : Q'\phi \leq \delta t + X'\beta; x_0^{'}\eta = 1; \phi \geq 0; \eta \geq 0\} \qquad (14)$$

The aggregated inputs and outputs of the Färe-Primont index are estimated as (O'Donnell, 2011):

$$Q_{it} = (q_{it}^{'}\alpha_0)/(\gamma_0 + x_0^{'}\beta_0) \qquad (15)$$

$$X_{it} = (x_{it}^{'}\eta_0)/(q_0^{'}\phi_0 - \delta_0) \qquad (16)$$

where α_0, β_0, γ_0, δ_0, η_0, ϕ_0 solve Eqs (15) and (16). DPIN-V3 uses sample mean vectors as representative output and input vectors in Eqs. (15) and (16). The representative technology in this LP is the technology obtained under the assumption of no technical change and allows the technology to exhibit variable returns to scale. For the computational details to estimate indices of productivity and efficiency measures using the DPIN-V3, see O'Donnell (2011).

3. Data

The data used for the analysis are constructed from various sources. The principal data on the Bangladesh agricultural sector are taken from the special issue of the Statistical Yearbook of Bangladesh which reports land area, production and yield of all major crops covering the period 1948-1972 (BBS, 1975), various issues of the annual Statistical Yearbook of Bangladesh covering the period 1975 to 2008 (BBS, various issues), agricultural databases covering the period 1948-1990 compiled and published by Hamid (1991, 1993), agricultural censuses of Pakistan 1960 (PMFA, 1960) and Bangladesh 1983-84, 1996 and 2008 (BBSa, various issues) and Ahmad (1958), population censuses of Pakistan 1951 and 1961 (PCO, various issues) and Bangladesh 1974, 1981, 1991, 2001, and 2011 (BBSb, various issues). The various variables are defined and constructed as follows. When data comes from separate censuses, data for the inter-census years were constructed using a standard linear trend interpolation model.

Crops (output) Includes all seasons and varieties of rice (*Aus*, *Aman*, and *Boro* – the pre-monsoon, monsoon and dry winter seasons), wheat, jute, sugarcane, potato, pulses, and oilseeds for each of the 17 regions (greater districts). All these variables are measured in physical quantities (i.e., metric tons), therefore, are largely free from aggregation issues that arises from using value equivalents

	expressed in constant prices (e.g., Dey and Evenson, 1991; Coelli *et al*., 2003; Rahman 2007). Six output variables are used: (a) food grain (includes all varieties of rice, wheat and other minor cereals), (b) sugarcane, (c) jute, (d) potatoes (including sweet potatoes), (e) pulses (all types, e.g., lentil, mungbean, gram, etc.), and (f) oilseeds (all types, e.g., mustard, sesame, rape, and groundnut).
Labour	Agricultural population (in thousands) for each region is used. Usable information on agricultural population appeared in agricultural censuses 1960, 1983-84, 1996 and 2008. Also, agricultural population by region was available for the 1951 Population Census of East Pakistan. Although definitions of 'agricultural population' across periods is likely to vary, nevertheless, this is a far closer measure of labour (both adult male and female) engaged in the sector than arbitrarily allocating all rural adult male population as labour input as done by previous studies.
Land area	Area (in thousand hectares) under all the crops included in the output series above is considered as the land area under cultivation. This measure of land area allows for changes in cropping intensity. Also, this measure of land area covers more than 90% of the gross cropped area of the country.
Animal power	Number of draft animals (i.e., cattle and buffaloes) is estimated using linear trend interpolation from actual counts available in the agricultural censuses of 1960, 1983-84, 1996 and 2008. The count for 1949 is taken from Ahmad (1958).
Fertilizer	Actual nutrient content (in metric tons) of three major types of fertilizers are used. These are: active ingredients of nitrogen (N), potassium (K) and

	phosphorus (P) from Urea, Triple Superphosphate, Single Superphosphate, Muriate of Potash, and Di-ammonium Phosphate fertilizers. Again this is preferable measure to the value aggregates at constant prices of all fertilizers as a single input, used in previous studies.
Irrigation	Proportion of total land area (above) under irrigation. The total area (in acres or hectares) under irrigation always appears in various Yearbooks of Statistics of Bangladesh and is easy to compute.

To summarize, six distinct outputs (foodgrains, sugarcane, jute, potatoes, pulses and oilseeds) and seven distinct inputs (land, labour, animal power, N, P, and K fertilizers and irrigation) are used to represent the production technology and to compute the productivity indices. In other words, the data are analysed in their most disaggregated form (given availability and practicality), allowing for reliable multi-temporal (61 years) and multi-lateral (17 regions) comparisons of productivity and efficiency, unlike any previous study of Bangladesh agriculture.

Agricultural productivity growth

The multi-lateral agricultural TFP indices and their various components are calculated for all the 17 regions covering a 61 year period 1948–2008. The results are summarized in Tables 1 and 2. The average TFP level is estimated at 0.46, technical efficiency level at 0.97, scale efficiency at 0.98, mix efficiency at 0.85, residual scale efficiency at 0.82 and residual mix efficiency level at 0.72 (Table 1). The implication is that Bangladesh farmers are doing well in terms of pure technical and scale efficiencies but not on mix efficiency, that is, the ability to derive economies of scope by changing optimal input and output mixes. Overall, TFP grew at an estimated annual rate of 0.57% which is modest but still encouraging because such a level of positive growth has been maintained for a record 61 year period (Table 2). This estimate of TFP growth is higher than the estimate of 0.32% p.a. by Pray and Ahmed

(1991) but lower than the estimates of 0.94% p.a. by Dey and Evenson (1991) and 0.90% p.a. by Rahman (2007) and in contrast with Coelli *et al*. (2003) who reported a decline in TFP of 0.23% p.a. instead. The present results are not strictly comparable because the previous TFP estimates are based on indices that are not multiplicatively complete or transitive. Our estimates are more reliable since the Färe-Primont index is free from most restrictive assumptions while satisfying all economically relevant axioms and validity tests from index number theory (O'Donnell, 2012). The growth in TFP has not been uniform and went through a cycle of fluctuation until the 1970s and then surged upward from 1985 which Rahman (2007) termed as the mature stage of GR technology adoption that was soon followed by reforms in the agricultural sector from the 1990s. The cycle of lower rates of TFP growth during the early stages of GR (i.e., the 1960s and 1970s), then rising during the post-GR period (i.e., the 1980s onward) agrees with results for India (e.g., Murgai, 2001; Mukherjee and Kuroda, 2003) as well as for Asia in general (e.g., Suhariyanto and Thirtle, 2001).

The observed growth in TFP is exclusively powered by technological progress, as expected, which grew at an annual rate of 0.74% (Table 2), a feature also noted by Coelli *et al*., (2003) and Rahman (2007). The contribution of technical efficiency change to TFP growth is almost negligible, only 0.01% p.a. Likewise, the decline in scale efficiency is negligible, 0.01% p.a. However, mix efficiency declined at an annual rate of 0.19%. The implication is that Bangladesh managed to maintain technical efficiency and scale efficiency over this long 61 year period but could not sustain mix efficiency change in the later years. This is evident from Table 2, which shows that technical efficiency and scale efficiency indices remained at or slightly above levels of 1.00 in most of the years. This finding is in contrast with Coelli *et al*., (2003) and Rahman (2007) who reported substantial falls in technical efficiency as the main feature of Bangladesh agriculture. Since the productivity changes have been decomposed into finer measures than conventionally reported in the literature, it is possible to correctly isolate the component (i.e., mix efficiency change) that is actually falling. In other words, farmers are unable to derive economies of scope by changing input and output mixes optimally in their production process. The inability to decompose the components of TFP changes into such finer measures of efficiency led the previous studies to incorrectly blame a decline in technical efficiency as the main cause of poor TFP growth in Bangladesh (e.g., Coelli *et al*., 2003; Rahman, 2007).

[Insert Tables 1, 2]

Although Tables 1 and 2 provide overall performance levels of the economy, they say nothing about the complex dynamics driving these productivity results. To demonstrate regional performance, the average annual growth rates of TFP and its components for the 17 regions are presented in Table 3. It is clear from Table 3 that the overall growth in agricultural productivity is led by Chittagong (3.5% p.a.) followed by Rajshahi, Rangpur, Dinajpur, Noakhali and Sylhet (showing TFP growth of above 1.0% p.a.). The Chittagong Hill Tracts and Khulna were the poor performing regions. The case of Chittagong Hill Tracts is understandable as this is not suitable for conventional agriculture. The region is characterized by mountainous terrain with most areas being classified as state forests and jhum (slash and burn) agriculture is the main feature practiced by the resident tribal population. Also, both Coelli *et al*., (2003) and Rahman (2007) excluded Chittagong Hill Tracts from the analysis altogether for this reason. Similarly, Khulna region is a coastal region with salinity problems. Instead, a large number of farmers there adopted the integrated prawn-fish-rice culture known locally as 'ghers' (Rahman *et al*., 2011). The poor performance of Dhaka has been noted by Dey and Evenson (1991) for the 1973-89 period but Rahman (2007) instead noted stagnancy during the early 1964-75 period and an overall growth of 1.4% p.a. for the entire 1964-1992 period.

It is also clear from Table 3 that a unique feature of the Chittagong region is its very high rate of technical efficiency improvements (0.79% p.a.) as well as scale efficiency improvements (0.29% p.a.) and small increase in mix efficiency change (0.03%). The other region Noakhali showed an increase in technical efficiency with an improvement of 0.23% p.a. A total of 11 regions experienced stagnant technical efficiency change (i.e., 0% growth) whereas the remaining four regions recorded technical efficiency declines. These are Khulna (0.27% p.a.), Barisal (0.20%), Sylhet (0.18%) and Comilla (0.02%). Khulna and Barisal are the coastal regions in the south and Sylhet is a hilly region at the upper northeast of the country. Ahmed (2001) also notes that the coastal, central and north-eastern regions have been stagnant in their growth performance since the take-off stage of the GR (i.e., 1980s onward) and continued to be so although there is no difference in the level of technology adoption as compared to fast growth regions.

[Insert Table 3 here]

4. Sources of TFP growth and its components

Once TFP and other efficiency indices are computed, the next step is to investigate the drivers and determinants of TFP change and its components. As such, six variables that are considered to be highly relevant and can be influenced by policy measures are used as the determinants. The definition and construction of these variables are as follows. Again, data for the inter-census years were constructed using a standard linear trend interpolation model.

Green Revolution technology	Share of HYV rice in Gross Cropped Area (GCA). This information is also readily available and easy to compute. The irrigated area is not used because it is significantly positively correlated with HYV rice area ($r = 0.84$, $p<0.01$). It is not possible to add HYV wheat and maize areas since they cannot be isolated in the dataset.
Herfindahl index of crop diversification	To analyse crop diversity, the Herfindahl index measure of crop

	concentration is used. $D_H = \sum \alpha_j^2$, $0 \le D_H \le 1$, where α_j = area share occupied by the *j*th crop in *A* (the Gross Cropped Area). A zero value denotes perfect diversification and a value of 1 denotes perfect specialization
Average farm size	Average farm size (ha per farm) is taken from the Census of Pakistan 1951 and agricultural censuses of 1960, 1983-84, 1996 and 2008.
Average literacy rate	Average literacy rate of population aged 7 years and above is taken from Census of Pakistan 1951 and 1961 and Bangladesh Population censuses of 1974, 1981, 1991, 2001 and 2011.
R&D expenditure	R&D expenditure data is converted to a series involving a time-lag to take account of the time required for the technology generated by the research system to reach the farmers for adoption (following Dey and Evenson, 1991). In order to take the lag into account, the weighted sum of research expenditures over a period of 14 years is used. The research variable is constructed as $\Sigma W_{t-i} R_{t-i}$, where W_i is a weight and R_{t-i} is research investment in year *t-i* measured at constant 1984-85 prices. The weight for the current year research expenditure is zero, for a one year lag the weight is 0.2, while for a 2 year lag it is 0.4, and so on (for details, see Dey and Evenson, 1991).
Extension Expenditure	Total extension expenditure incurred by the MoA and/or the Department of Agricultural Extension (in million taka) at constant 1984-85 prices is used. Data prior to 1972 are collected from the

Pakistan Planning Commission reports.

In order to identify the determinants of TFP change and its components, we use the Generalised Least Squares (GLS) Random Effects model for panel data. We use this approach in order to account for any systematic effect of the regions as well as time-varying effects of the explanatory variables. The basic model is specified as follows:

$$y_{kit} = \alpha + \boldsymbol{\beta}\mathbf{X}_{it}^{'} + u_i + \varepsilon_{it} \qquad (17)$$

where y_k is the index of TFP change and/or its components (k = 1, 2, …5); X is the matrix of regressors, β is the vector of parameters, u_i is the unit specific random element distributed as *IID* (0, σ_u^2) and is assumed to be independent of ε_{it} and $\mathbf{X}_{it}$; and ε_{it} is distributed as *IID* (0, σ_ε^2).

Table 4 presents the elasticities (computed from the parameter estimates) along with the model diagnostics from the estimation of Eq. (17). The parameters σ_u and σ_ε are the sources of variations, the former is from the heterogeneity of regions and the latter is from idiosyncratic errors or noise and ρ is the intraclass correlation or the fraction of variance due to u_i. The model diagnostics reveal that regional heterogeneity and idiosyncratic errors explain very little about the variation in TFP change and its components, reflected by low values of these three parameters. Instead, variations in TFP change and its components are explained largely by the six policy amenable variables used in the regression which is confirmed by the Wald χ^2 statistics (bottom section of Table 4).

The GR technology is a significant determinant of technical change (as expected) as well as scale efficiency change although this has no significant influence on TFP growth (Table 4). Coelli *et al*., (2003) however noted a significant influence of GR technology on technical change, technical efficiency change and TFP growth. This may be due to the specification of their GR technology variable. They included wheat and maize areas with the

HYV rice area to create the HYV crop share variable and then multiplied it by the irrigated area share to break any correlation between the two. Next, it can be seen that although crop diversification significantly positively influences technical change and technical efficiency change, crop specialization leads to significant TFP growth. There may be two reasons for this. First, specialization in the Bangladesh context refers to cereal production, which is made up of traditional varieties of rice, HYV rice, wheat and maize. Therefore, even though the GR technology (i.e., the share of HYV rice in GCA) does not directly contribute to TFP growth, the concentration of land devoted to cereals (which includes the HYV rice area) invariably contributes positively to TFP growth. Second, the use of high yielding varieties amongst non-cereals is almost non-existent except for potatoes, resulting in a low yield. Farm level evidence shows that crop diversity positively influences technical efficiency (Rahman, 2009), which is also found here.

Literacy rates significantly influence technical change but work against technical and scale efficiency changes and TFP growth. This finding corroborates Deb (1995) as well as the farm-level study by Coelli *et al*., (2002) who noted that the education system in Bangladesh is not correlated with efficiency. Pritchett (2001) also argued that educational quality in developing countries could have remained so low that years of schooling created no human capital.

Average farm size significantly influences technical and scale efficiency changes and TFP growth as expected. It is also one of the most dominant determinants as indicated by the elasticity values. For example, a 1% increase in average farm size will increase TFP by 0.24% which is substantial.

The influence of R&D expenditure is also strongly positive on technical change, technical efficiency and scale efficiency changes and TFP, and is the second most dominant determinant of TFP growth with an elasticity value of 0.13. Coelli *et al*., (2003) also showed a positive influence of R&D investment on technical change and TFP change but a negative influence on technical efficiency change.

Finally, extension expenditure positively influences mix efficiency change and TFP growth but negatively influences technical change. The present result partially agrees with Coelli *et al*., (2003) who reported a negative influence of extension expenditure on technical change and TFP growth and positive influence on technical efficiency change. They argued that the main role of extension is to assist farmers to move closer to the frontier which is correctly identified here with significant influence on mix efficiency change, i.e., enabling farmers to derive scope economies from their production process by changing input and output mixes to optimal levels. The implication is that the extension workers are advising farmers on the most productive input and output mixes.

[Insert Table 4 here]

5. Conclusions and policy implications

This paper applies the Färe-Primont index (O'Connell, 2012) to calculate TFP indices for agriculture in 17 regions of Bangladesh covering a 61 year period (1948 to 2008) and decomposes the TFP index into six components (technical change, technical, scale and mix efficiency changes, residual scale and residual mix efficiency changes). The paper also identifies the sources of growth of TFP change and its components using a set of six policy relevant variables.

Results reveal that TFP grew at an average rate of 0.57% p.a., led by Chittagong, Rajshahi, Rangpur, Dinajpur and Noakhali regions. TFP growth is largely powered by an estimated 0.74% p.a. growth in technological progress. The contribution of technical efficiency change and scale efficiency change is negligible, estimated at 0.01% p.a. and -0.01% p.a. respectively, due to stagnancy in efficiency levels in most of the regions. However, mix efficiency declined at a rate of 0.19% p.a. The implication is that Bangladesh has been able to maintain technical efficiency over a long period but experienced a decline in exploiting economies of scope from optimal mixes of inputs and outputs in their production process in the later years. Analysis of the sources of growth reveals that the drivers exert differential impacts on different components of TFP change. The dominant drivers of TFP growth are average farm size, crop specialization, R&D investment and extension expenditure, whereas literacy rate influences TFP growth negatively (reflecting exodus of the better educated from agriculture).

The main policy implications are as follows. First, Bangladesh needs land reform measures aimed at increasing average farm size by land consolidation which will significantly influence TFP growth as well as various efficiency measures as it is the most dominant determinant of TFP growth. Average farm size in Bangladesh has been falling steadily from 1.4 ha in 1960 to 0.60 ha in 2008. Rahman and Rahman (2009) noted that land fragmentation, which is intricately linked to a reduction in farm size, significantly negatively influences technical efficiency and productivity.

Second, the need for increased investment in R&D is undisputed as it would improve TFP growth and most of its efficiency components and is the second most important determinant of TFP growth. Bangladesh needs to continue promotion of cereal based GR technology as it will directly contribute to technical change and scale efficiency change and then contribute indirectly to TFP growth through crop specialization dominated by cereals (i.e., rice, wheat and maize). The previous thrust in GR diffusion over the past four decades has paid off to a large extent and Bangladesh has achieved self-sufficiency in food grain production with improvements in food availability per person and a reversal of the dietary imbalance in energy intake from field crops in recent years (Rahman, 2010).

Third, parallel promotion of crop diversification by investing in new technologies for non-cereals will positively contribute to technical change and technical efficiency change. In recent years, the government has opted to promote crop diversification which is a step in the right direction as it significantly improves technical efficiency as well as use significantly less resources at the farm level (Rahman, 2009). Also, Sen (2003) noted that those farmers who adopted multiple strategies (i.e., agricultural intensification, crop diversification, off-farm activities, and livelihood migration) were better able to escape poverty in rural Bangladesh.

Finally, investment in extension expenditure will directly influence mix efficiency change, which is declining sharply, as well as improve TFP growth. Increased investment in extension will enable some farmers to address their failing to derive economies of scope by applying optimal input and output mixes from their production process.

The challenge to realize all these measures are formidable but Bangladesh needs to maintain or even increase the observed rate of TFP growth in order to sustain and raise the standards of living of its population to a level that is fit for the 21st century.

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Table 1. TFP and efficiency levels (selected years).

Year	Maximum TFP level	Technical efficiency levels	Scale efficiency level	Mix efficiency levels	Residual scale efficiency levels	Residual mix efficiency levels	TFP levels
	1	2	3	4	5	6	7 = (1*2*3*6) = (1*2*4*5)
1948	0.48	0.96	0.97	0.96	0.85	0.84	0.38
1949	0.52	0.98	0.98	0.96	0.84	0.82	0.41
1950	0.52	0.92	0.95	0.95	0.87	0.87	0.39
1955	0.60	0.98	0.98	0.96	0.83	0.81	0.47
1960	0.70	0.97	0.98	0.94	0.79	0.76	0.51
1965	0.70	0.96	0.97	0.93	0.82	0.78	0.51
1970	0.70	0.98	0.99	0.90	0.81	0.74	0.50
1975	0.70	0.90	0.96	0.80	0.77	0.64	0.39
1980	0.70	0.94	0.99	0.78	0.80	0.63	0.41
1985	0.70	0.99	0.99	0.83	0.79	0.65	0.45
1990	0.70	0.97	0.98	0.73	0.84	0.63	0.42
1995	0.70	0.97	0.99	0.79	0.80	0.64	0.43
2000	0.70	0.99	0.99	0.84	0.84	0.71	0.49
2001	0.70	0.99	0.99	0.84	0.89	0.75	0.52
2002	0.70	0.99	0.99	0.81	0.89	0.73	0.50
2003	0.70	0.99	0.99	0.82	0.90	0.74	0.51
2004	0.70	0.99	0.99	0.86	0.88	0.76	0.53
2005	0.70	0.98	0.99	0.82	0.87	0.72	0.49
2006	0.70	0.99	0.98	0.82	0.86	0.72	0.49
2007	0.70	0.98	0.98	0.83	0.87	0.74	0.50
2008	0.70	0.96	0.97	0.85	0.89	0.77	0.51
Geomean	0.67	0.97	0.98	0.85	0.82	0.71	0.46

Table 2. TFP change and its components (selected years).

Year	Technical change	Technical efficiency change	Scale efficiency change	Mix efficiency change	Residual scale efficiency change	Residual mix efficiency change	TFP change
	1	2	3	4	5	6	7 = (1*2*3*6) = (1*2*4*5)
1948	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1949	1.07	1.02	1.00	1.00	0.99	0.99	1.08
1950	1.07	0.96	0.98	0.99	1.03	1.04	1.04
1955	1.24	1.02	1.01	1.00	0.98	0.97	1.24
1960	1.45	1.02	1.00	0.98	0.93	0.91	1.36
1965	1.45	1.01	0.99	0.97	0.96	0.94	1.36
1970	1.45	1.02	1.01	0.93	0.95	0.89	1.32
1975	1.45	0.94	0.99	0.84	0.91	0.77	1.04
1980	1.45	0.98	1.02	0.81	0.95	0.76	1.10
1985	1.45	1.03	1.03	0.87	0.93	0.78	1.20
1990	1.45	1.01	1.01	0.76	0.99	0.75	1.11
1995	1.45	1.02	1.02	0.82	0.94	0.76	1.14
2000	1.45	1.03	1.01	0.88	0.98	0.85	1.30
2001	1.45	1.04	1.02	0.87	1.05	0.90	1.38
2002	1.45	1.04	1.02	0.84	1.05	0.87	1.33
2003	1.45	1.04	1.02	0.85	1.06	0.89	1.37
2004	1.45	1.03	1.02	0.90	1.04	0.91	1.39
2005	1.45	1.03	1.02	0.85	1.03	0.86	1.31
2006	1.45	1.04	1.01	0.85	1.01	0.86	1.30
2007	1.45	1.02	1.01	0.86	1.03	0.88	1.31
2008	1.45	1.01	1.00	0.88	1.04	0.92	1.35
Growth rate (%)	0.74	0.01	-0.01	-0.19	0.07	-0.12	0.57

Table 3. Growth rates of TFP change and its components by regions.

Region	Average annual growth rates (%)							
	Technical change	Technical efficiency change	Scale efficiency change	Mix efficiency change	Residual scale efficiency change	Residual mix efficiency change	TFP change	Rank
Chittagong	0.74	0.79	0.29	0.03	0.63	0.33	3.35	1
Rajshahi	0.74	0.00	0.08	0.14	0.25	0.32	1.35	2
Rangpur	0.74	0.00	0.00	0.27	0.03	0.31	1.19	3
Dinajpur	0.74	0.00	0.00	0.00	0.30	0.30	1.18	4
Noakhali	0.74	0.23	-0.05	-0.13	0.17	0.08	1.12	5
Sylhet	0.74	-0.18	0.23	-0.05	0.47	0.17	1.02	6
Mymensingh	0.74	0.00	0.00	0.00	0.15	0.15	0.96	7
Jessore	0.74	0.00	0.00	-0.01	0.08	0.07	0.85	8
Bogra	0.74	0.00	0.00	0.13	-0.23	-0.11	0.58	9
Barisal	0.74	-0.20	-0.00	-0.13	0.23	0.08	0.56	10
Comilla	0.74	-0.02	0.02	-0.21	-0.02	-0.24	0.39	11
Pabna	0.74	0.00	0.00	-0.05	-0.23	-0.27	0.36	12
Faridpur	0.74	0.00	0.00	-0.19	-0.17	-0.33	0.26	13
Kushtia	0.74	0.00	0.00	-0.45	-0.01	-0.45	0.08	14
Dhaka	0.74	0.00	0.00	0.00	-0.53	-0.53	-0.02	15
Khulna	0.74	-0.27	-0.08	-0.47	0.21	-0.25	-0.03	16
Chittagong Hill Tracts	0.74	0.00	-0.46	-1.20	0.25	-0.94	-0.91	17
Bangladesh	0.74	0.01	-0.01	-0.19	0.07	-0.12	0.57	

Table 4. Determinants of TFP change and its components

Variable	Elasticities (Random effects GLS model)				
	Technical change	Technical efficiency change	Scale efficiency change	Mix efficiency change	TFP change
Green Revolution technology	0.015	0.002	0.006	-0.023	-0.017
	(3.61)***	(0.60)	(2.36)**	(-2.44)**	(-1.45)
Herfindahl index of crop diversification	-0.026	-0.056	-0.005	-0.025	0.163
	(-2.22)***	(-3.43)***	(-0.52)	(-0.54)	(2.88)***
Literacy rate	0.045	-0.043	-0.022	0.019	-0.151
	(3.43)***	(-2.74)***	(-2.34)**	(0.50)	(-3.05)***
Average farmsize	0.013	0.025	-0.000	0.187	0.240
	(1.55)	(2.66)***	(-0.04)	(8.19)***	(8.27)***
R&D investment	0.032	0.021	0.007	-0.000	0.126
	(4.52)***	(3.02)***	(1.68)*	(-0.04)	(5.99)***
Extension expenditure	-0.019	0.002	-0.000	0.021	0.022
	(-6.76)***	(0.93)	(-0.27)	(3.89)***	(3.10)***
σ_u	0.001	0.018	0.011	0.094	0.155
σ_e	0.104	0.056	0.035	0.113	0.212
ρ (fraction of variance due to u_i)	0.000	0.092	0.095	0.411	0.347
Wald χ^2 (6 d.f.)	288.83***	66.51***	35.93***	206.35***	170.97***
N	1036	1036	1036	1036	1036

Note: Figures in parentheses are z-values.
*** = significant at 1% level (p<0.01)
** = significant at 5% level (p<0.05)
* = significant at 10% level (p<0.10).

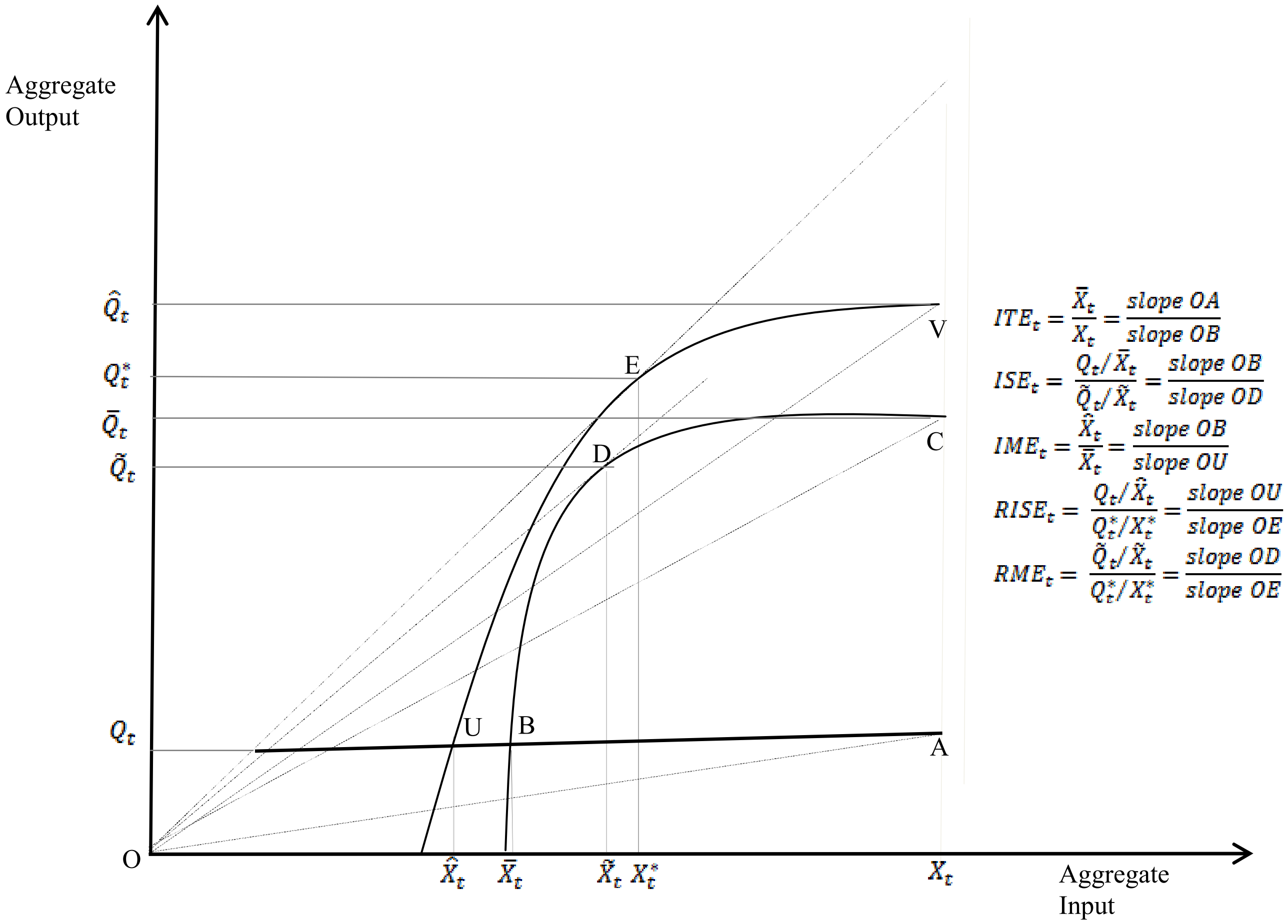

Figure 1: Technical, scale and mix efficiency of a multi-input multi-output firm.

Source: Adapted from Figure 3 of O'Donnell (2012a).