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PRODUCTIVITY GROWTH AND EFFICIENCY CHANGES IN PRAWN-CARP–RICE FARMING IN 'GHER' SYSTEM IN BANGLADESH: A FÄRE-PRIMONT INDEX APPROACH

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ABSTRACT

'Gher' farming system refers to the joint operation of three enterprises: freshwater prawn, carp and HYV rice practiced widely in the southwestern coastal Bangladesh. The paper estimates growth in total factor productivity (TFP) and its six finer components (technical change, technical, scale and mix efficiency changes, residual-scale and residual-mix efficiency changes) of the prawn-carp-rice joint culture and identifies their determinants by exploring a panel database of a cohort of 90 'gher' farms over a 13-year timespan (2002-2014) from southwest Bangladesh. The aim is to judge sustainability of this unique farming system. Results revealed that TFP grew @ 0.86% p.a. mainly powered by technical change @ 0.54% p.a. and mix-efficiency change @0.06% p.a. while technical and scale efficiency changes declined @ 0.17% and 0.10% p.a., respectively. Farm-level socio-economic factors exerted differential impacts on TFP growth and its components. The key conclusion is that the 'prawn-carp-rice' joint culture in 'gher' system is sustainable and has the potential to support growth of the broader agricultural sector and the Bangladesh economy. Experience and education, 'gher' area, share of family labour and tenancy significantly improved TFP growth and technical change. The policy interventions include additional funds in education for 'gher' farmers, land and tenurial reforms to consolidate operation size and training for female labourers to improve long-term growth of the 'prawn-carp-rice' joint farming.

JEL Classification: C23, O33; Q12

Keywords: productivity growth; efficiency change; prawn-carp-rice joint culture; socio-economic factors; farm-level panel data; Bangladesh.

1. Introduction

Fish and fisheries products are not only the source of nutritious food but also offer several other benefits ranging from employment, income, rural development, export earnings and maintaining ecological and environmental balances. Most importantly, during the last six-decades, the growth rate in fish consumption outpaced population growth and animal meat consumption (FAO, 2018). At the global level, many development goals and targets are related to fisheries, particularly the Sustainable Development Goals (SDG 14). In 2016, global fish production has reached its historical peak (171 million tonnes) of which 47% are from aquaculture. Bangladesh contributes 2.8% of world's total aquaculture production and is the world's fifth largest producer (FAO, 2018).

In crop dominated Bangladesh agriculture, aquaculture has its own importance. The fisheries sector contributes around 3% of the total national Gross Domestic Product (GDP) (MoF, 2018), employs around 25.7 million people (BBS, 2011) and supplies more than 50% of total animal protein (FAO, 2018). Shrimp and prawn have its own importance globally (accounting for 6.2% of total value of traded fish and fish products) (FAO, 2018) as well as in Bangladesh (accounting for more than 85% of total value of exported fish and fish products) (FRSS, 2017). Though shrimp have more profound impact on national economy than prawn, shrimp farming is heavily blamed for their adverse socioeconomic and environmental impacts (e.g. Primavera, 1997; Pàez-Osuna, 2001; Bush et al., 2010) whereas similar concerns are not raised for prawn cultivation (e.g. Csavas1993; Phillips et al., 1993).

Bangladesh's agro-climatic conditions and natural resource base suit well for freshwater prawn (*Macrobrachium rosenbergii*) farming (Rahman et al., 2011), and the country is successfully reaping the advantages. The freshwater prawn cultivation is increasingly gaining importance in the country, as it does not only generate higher farm profit but also earns foreign currency. In Bangladesh shrimp and prawn is cultivated in 272,717 ha of land (FRSS, 2017) and around 315,000 farmers are involved with prawn farming in the 'gher' system[1] (DoF, 2012). Bangladesh exported 39,706 mt of prawns and shrimps worth USD 457 million in 2016/17 of which 17% of the total quantity and 22% of the total value of export was contributed by prawn (FRSS, 2017). Though prawn farming technology in Bangladesh is mainly of low-intensive type, its full potential is yet to be explored. For instance, by expanding existing low-intensive practice to another 10% and 50% of the total potential area of 55,000 ha in the southwest region, Bangladesh can annually receive an additional income of USD 14 and USD 70 million through export, respectively (Ahmed and Flaherty, 2013). Although the nominal export value of shrimp and prawn declined by 11% for four years up to 2016-17, the actual quantity exported in 2016-17 was the lowest of the last 14 years (FRSS, 2017). Such continued decline indicates that the option to expand 'gher' areas may not be feasible for Bangladesh because this highly populated country is continuously experiencing diversion of agricultural land for non-agricultural purposes @ 1% p.a. (PC, 2009). Therefore, the alternative lies in enhancing productivity of the 'gher' farming system to sustain and support agricultural growth in the economy in the future.

In a 'gher', a farmer excavates canal so that water enters the crop field and builds higher dikes surrounding the field so that water can be held for the dry winter months (Kendrick, 1994). These adjustments ultimately enable the farmer to jointly operate three enterprises: freshwater prawn, carp and High Yielding Variety (HYV) Boro (dry season) rice (Kamp and Brand, 1994; Rahman et al., 2011), thereby leading them to meet their requirement of major staple (i.e. rice) and cash income (e.g. prawn and carp) simultaneously. This 'blue revolution' is extensively practiced in the southwestern coastal Bangladesh (Ito, 2004), and nearly 70% of the freshwater prawn in the region is produced in 'gher' (Rahman et al., 2011). The significant role of 'ghers' in aquaculture as a high-income earning and productive agricultural enterprise

[1] Farmers in southern region of Bangladesh do not practice prawn monoculture. Instead they operate under the highly rewarding 'gher' farming system although their main focus is to maximize revenue from prawn production because of its high market value and export demand.

is well documented in the literature (Movik et al., 2005; Ahmed et al., 2008).

Study on long-term productivity growth of 'gher' farming is not available. Only a few cross-sectional studies analyzing productivity and efficiency levels of 'gher' farms (e.g., Rahman et al., 2011; Rahman and Barmon, 2012) in addition to a couple of older studies exploring production efficiency of shrimp farms (e.g., Shang et al., 1998; Rashid and Chen, 2002) exist. All these studies noted that although prawn and/or shrimp farming are profitable, the level of efficiency is low and there is strong potential to improve productivity through better utilization of resources. A major limitation of these studies is that they only provide a snapshot of the existing situation, but do not provide any insights about the level of productivity and efficiency changes over time, which is essential to judge the future growth potential of this unique farming system.

Total Factor Productivity (TFP) indices can capture the effects of technological progress as outcomes of research and development over time (Mukherjee and Kuroda, 2003). While ensuring higher output from the available technology and resources base, higher TFP contributes in reducing rural poverty (Fan *et al*., 2000), a core policy agenda for any developing country government including Bangladesh. Hence, it is very important to examine long-term productivity performance of this unique and highly promising 'gher' farming system, so that appropriate policies can be devised to further enhance its potential to support growth of the Bangladesh economy. Enhancing productivity has more appeal in Bangladesh, where yield of prawn is significantly lower than other Asian countries, such as India, China, Thailand, Vietnam and Taiwan. For instance, prawn yield in Bangladesh is 50% and 85% lower than India and Thailand, respectively (Ahmed et al., 2008).

At this backdrop, this study proceeds with the objectives to: (a) evaluate changes in Total Factor Productivity (TFP) and its six components (i.e., technical change, technical efficiency change, scale efficiency change, mix efficiency change, residual-mix efficiency change, and residual-scale efficiency change) of 'gher' farms over time; and (b) identify socio-economic drivers of TFP change and its associated components. Our work is based on a unique balanced panel dataset of a cohort of 90 'ghers' over a period of 13-years (2002–2014) operating in southwest Bangladesh.

Following are contributions of the present research to existing pool of literature. Prior to this study, there were no effort to estimate productivity growth of 'ghers' over time in order to judge its potential to support future growth of the broader agricultural sector. Secondly, we decompose the TFP index into its six finer measures, whereas productivity literature usually informs only two or three measures (i.e., technical change, technical efficiency change and/or scale efficiency change). Such detailed information will enable us to gather more insights about the long-term performance of the 'gher' farming system. And third, the method we have applied (i.e., the Färe-Primont index using a programming approach) is idyllic as it fulfils all the economically pertinent axioms and tests suggested for index number theory (e.g. transitivity and identity tests) and is a trusted measure for comparing multi-temporal (many periods) and/or multi-lateral (many farms) indices of TFP and efficiency (O'Donnell, 2012a). Most importantly, the Färe-Primont index is argued to be flexible in nature as it does not adopt any restrictive assumptions regarding the production technology, price and behaviour of the farms or the competition level that exists in the input or output markets (O' Donnell, 2012b, 2012c). In addition, the most commonly used productivity index, i.e., the Malmquist Index, which also do not require information on price and behaviour of the farms or the competition level, is biased and fails to satisfy transitivity as well as axioms of the index number theory (O'Donnell, 2010, 2012a). For example, Le Clech and Castejón (2017) compared agricultural TFP using Malmquist and Fare-Primont Index on the same global database and concluded superiority of the later approach.

The paper contains seven sections. Following this introduction section, Section 2 briefly describes the context and operation of the Bangladeshi 'gher' farms. Section 3 describes the method, followed by introduction to data and the variables in Section 4. Section 5 reports and interprets results. Section 6 identifies and explains drivers of TFP growth and its different components. Section 7 concludes the paper by offering some policy options.

2. The 'prawn-carp-rice' farming in the 'gher' system

As mentioned earlier, a 'gher' farm constitutes transformation of a rice land to operate three enterprises: carp, prawn and HYV Boro rice. During monsoon (i.e., June to December) the 'ghers' are filled with rain water, which otherwise remains dry during January to April except the canals (see Figure 1). During the beginning of 'gher' cycle (June), farmers release post-larvae of the freshwater prawn into the 'gher'. A wide range of supplementary feed (e.g., snail meat, home-made and commercially sourced feed) is provided to prawn during the growing period to boost its production. Labour is extensively used in 'gher' as the surrounding dikes and trenches generally require considerable amount of annual restorations and repair. During May-June farmers release carp fingerlings in the 'gher' which are cultured for about nine months. Carps and prawns share the supplied feed. The HYV *Boro* rice cultivation inside the 'gher' takes place between January and April. Farmers irrigate rice-field within the 'gher' with water from the canal and saves substantially on supplementary irrigation costs.

2.1 Stocking density of prawn and fish fingerlings in the 'gher' system

The average stocking density of prawn fingerlings varies from 25,000–35,000 per ha in fresh water-based prawn-carp-rice farming in Bangladesh which is similar with the prawn stocking density of 30,100 per ha in India (Thangadurai, 1991). Chandra et.al. (2010) reported that the average stocking density of prawn fingerlings is about 36,330 per ha in the southern Bangladesh whereas the stocking density of carp-fingerlings range between 1,000–2,000 per ha. The average size of carp stock is 12-15 pieces per kg.

2.2 Grade and yield of prawn

There are four grades of harvested prawn depending on the size. These are: Grade–A (i.e., 5–10 pieces of prawn = 1 kg), Grade–B (i.e., 20–25 pieces of prawn = 1 kg), Grade–C (i.e., 30–35 pieces of prawn = I kg) and Grade–D (i.e., 40–50 pieces of prawn = 1 kg). In a typical 'gher' farm, the proportion of Grade–A, Grade–B, Grade–C and Grade–D sized prawns are approximately 10%, 50%, 30% and 10% of total production, respectively. Prawns smaller than Grade–D size are retained in 'gher' rather than harvested. The average annual prawn productivity ranges from 550–600 kg/ha and carp productivity vary between 500–600 kg/ha in prawn-carp-rice farming system in Bangladesh (Al-Amin and Alam, 2016).

3. Methodology

We have applied the Data Envelopment Analysis (DEA) linear program (LP), which is non-parametric in nature, to estimate productivity and efficiency changes of 'gher' farming in southwest Bangladesh. This unique approach is adopted as it enables us to estimate different relevant change indicators including: (a) technical change (i.e. movements along the production frontier); (b) technical efficiency change (i.e. moving towards or away from the frontier); (c) scale efficiency change that captures the economies of scale (i.e. movements around the frontier surface); and (d) mix efficiency change that helps to realize the economies of scope (i.e. movements around the frontier) (O'Donnell, 2010).

3.1 The Färe-Primont index to measure Total Factor Productivity

The TFP for a farm producing multiple outputs using multiple inputs can be derived as (O'Donnell, 2010):

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

where $Q_{it} = Q(q_{it})$and $X_{it} = X(x_{it})$are an aggregated output and input, respectively. Both the underlying output and input functions are assumed to be non-negative, non-decreasing and linearly homogeneous aggregator functions. The associated index number to measure TFP of the *i* th farm in *t* time period relative to TFP of farm *h* in *s* period is (O'Donnell, 2011a, 2011b):

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

$Q_{hs,it} = Q_{it}/Q_{hs}$ and $X_{hs,it} = X_{it}/X_{hs}$ are output and input quantity index, respectively. The TFP change is simply output change relative to input change.

O'Donnell (2011b) suggested following general form of the Färe-Primont function:

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

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

where q and x are the input and output vectors and $D_O(.)$ and $D_I(.)$ are the distance functions of output and input. The Färe-Primont TFP index can be estimated as (O'Donnell, 2011b):

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

The above index is generated by calculating the distance functions using O'Donnell (2010, 2011a) developed DEA methodology (details of the linear programming technique is available in O'Donnell (2011a, 2011b).

3.2 Efficiency measures

Most of the economic measures of efficiency are ratio measures of TFP and their detailed descriptions and definitions are available in O'Donnell (2011a; 2012b). These different measures of efficiency changes are derived through decomposing TFP indices.

These efficiency measures are estimated and described in the context of two production frontiers: one is a mix-restricted production frontier (where the ratios of outputs and inputs are unchanged) and the other is the unrestricted production frontier (which allows variable combinations of inputs and outputs), where all the points represent a particular input and output mix (for details, see Figure 1 in O'Donnell, 2012b).

The output-oriented technical efficiency (OTE) measures productivity shortfall associated with operating below the production frontier (O'Donnell, 2014) and is defined as the maximum output that can be produced by given level of inputs. The output-oriented scale efficiency

(OSE) measures the level of efficiency that can be derived due to economies of scale, i.e., varying operation size. The output-oriented mix efficiency (OME) measures the potential to change productivity when restriction on the mix of outputs and inputs are relaxed and it depends on the economies and diseconomies of scope. The measure of residual output-oriented scale efficiency (ROSE) is the ratio of TFP at a technically and mix-efficient point to the maximum TFP that is possible. The term residual is used to reflect that although all the points on the unrestricted production frontier are mix-efficient, each point has different input and output mixes (Rahman and Salim, 2013; O'Donnell, 2011a). The residual mix efficiency (RME) 'can be viewed as the component that remains after accounting for pure technical and pure scale efficiency effects' (O'Donnell 2012a: 263). This involves movement from an optimum point of the mix-restricted production frontier to the optimum point on the unrestricted production frontier (Rahman and Salim, 2013, O'Donnell, 2012a). These efficiency measures are presented in Eq. 6 through 10.

$$OTE_{it} = \frac{Q_{it}/X_{it}}{\bar{Q}_{it}/\bar{X}_{it}} = \frac{Q_{it}}{\bar{Q}_{it}} = D_O(x_{it}, q_{it}, t) \leq 1 \quad (6)$$

$$OSE_{it} = \frac{\bar{Q}_{it}/X_{it}}{\tilde{Q}_{it}/\tilde{X}_{it}} \leq 1 \quad (7)$$

$$OME_{it} = \frac{\bar{Q}_{it}/X_{it}}{\hat{Q}_{it}/X_{it}} = \frac{\bar{Q}_{it}}{\hat{Q}_{it}} \leq 1 \quad (8)$$

$$ROSE_{it} = \frac{\hat{Q}_{it}/X_{it}}{Q^*_{it}/X^*_{it}} \leq 1 \quad (9)$$

$$RME_{it} = \frac{\tilde{Q}_{it}/\tilde{X}_{it}}{Q^*_{it}/X^*_{it}} \leq 1 \quad (10)$$

where $TFP^*_t = Q^*_{it}/X^*_{it}$ is the highest attainable TFP at the available technology in *t* time period; $\bar{Q}_{it} = Q_{it}D_O(x_{it}, q_{it}, t)$ shows the maximum aggregated output produced from a scalar of *i*th number of inputs (x_{it}) producing multiple outputs (q_{it}); $\tilde{Q}_{it}$ is the mix of aggregated outputs whereas $\tilde{X}_{it}$ is that of inputs at a point called mix-invariant optimal scale (MIOS), i.e. the point at which a straight line from the origin becomes tangent with the mix-restricted production frontier; $\hat{Q}_{it}$ and $\hat{X}_{it}$ are the aggregated quantities of outputs and inputs at the point where the farm has highest TFP, conditioned that both the output and input vectors are scalar multiples of q_{it} and x_{it}, respectively (O'Donnell, 2012b).

Eq. (6) shows aggregate output maximized with a given aggregate input level and is the most popularly used technique for deriving output-oriented technical efficiency. By dividing TFP at a technically efficient point with the MIOS associated TFP, the scale efficiency, i.e. the efficiency resulting from economies or diseconomies of scale (i.e., allowing operation size to vary) is derived (Eq. 7). Mix efficiency, which relates the economies or diseconomies of scope in production, measures the potential productivity change by varying input and output mix (Eq. 8). This efficiency component is closely linked with the cost-allocative efficiency and is the ratio of two technical efficiencies, the denominator is on the mix-restricted frontier and the numerator is measured at the point on the unrestricted frontier. Eq. (9) presents residual-scale efficiency derived as the ratio of TFP at a technically- and mix-efficient point to TFP at the productivity maximization point. Finally, by dividing TFP at a point of MIOS with the TFP at a point of maximum productivity, one can derive residual-mix efficiency that represents movement from an optimal point on the mix-restricted frontier to the optimal point on the unrestricted frontier, which is a mix-effect. The term residual implies that such movement may be associated with scale changes (for more details please consult O'Donnell, 2012b).

3.3 The different components of TFP change

Following O'Donnell (2011b), the different components representing TFP changes that are multiplicatively complete are derived as:

$$TFP_{hs,it} = \left(\frac{TFP_t^*}{TFP_s^*}\right)\left(\frac{OTE_{hs}}{OTE_{hs}}\right)\left(\frac{OSE_{hs}}{OSE_{hs}}\right)\left(\frac{RME_{hs}}{RME_{hs}}\right)$$

$$= \left(\frac{TFP_t^*}{TFP_s^*}\right)\left(\frac{OTE_{hs}}{OTE_{hs}}\right)\left(\frac{OME_{hs}}{OME_{hs}}\right)\left(\frac{ROSE_{hs}}{ROSE_{hs}}\right) \quad (11)$$

The first ratio in parenthesis of the right-hand side of the above equation is a natural measure of technical change that compares the maximum TFP associated with the use of unrestricted technology in two different time periods (e.g. between *t* and *s* time periods). The other terms in the parentheses are described in Eqs. (6) to (10). Higher (or lower) than unity value of these ratios imply that the farm has become more (or less) efficient in respective *t* and *s* periods, while the available technology is unchanged. When the efficiency scores remain unchanged across the two time periods, the ratio values become unity (Rahman and Salim, 2013).

3.4 Data Envelopment Analysis: Empirical estimation

The (local) output distance function based on the necessary assumption of DEA for the available technology in *t* period is (O'Donnell, 2011a):

$$D_0(x_{it}, q_{it}, t) = (q_{it}^{'}\alpha)/(\gamma + x_{it}^{'}\beta)(12)$$

The output-oriented solution requires selecting unknown parameters values for the Eq. (12) for minimizing technical efficiency: $OTE_{it}^{-1} = D_O(x_{it}, q_{it}, t)^{=1}$. The associated LP is:

$$D_O(x_{it}, q_{it}, t) = OTE^{-1} = \min_{\alpha,\gamma,\beta}\{\gamma + x_{it}^{'}\beta : \gamma t + X'\beta \geq Q'\alpha : q_{it}^{'}\alpha = 1; \alpha \geq 0; \beta \geq 0\}(13)$$

where the outputs $\boldsymbol{Q}$ is a J x M_t matrix, the inputs $\boldsymbol{X}$ is a K x M_t matrix, t is a $M_t\ x1$ unit vector, and M_t is the number of observations used for estimating the frontier in *t* period (O'Donnell, 2011a). The DPIN-V3 programme utilizes the following variant of this LP while computing different components of productivity and efficiency measures (O'Donnell, 2011a):

$$D_O(x_0, q_0, t) = OTE^{-1} = \min_{\alpha,\gamma,\beta}\{\gamma + x_0^{'}\beta : \gamma t + X'\beta \geq Q'\alpha : q_0^{'}\alpha = 1; \alpha \geq 0; \beta \geq 0\}(14)$$

O'Donnell (2011a) suggested the following two equations for aggregated outputs and inputs:

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

$$X_{it} = (x_{it}^{'}\eta_0)/(q_0^{'}\varphi_0 - \delta_0)(16)$$

The parameters of the above two equations are estimated using the software DPIN-V3, which calculates sample mean vectors of the outputs and inputs. The LP here assumes no technical change and variable returns to scale (details of the computation are available in O'Donnell

2011a).

4. Data and variables

The primary data required for this study were generated through 13-rounds of primary surveys during the years 2002-14 with the 'gher' farmers living in the Bilpabla village situated in the Dumuria sub-district of the Khulna District. The village was purposively selected as it is a typical southwestern Bangladeshi village and the farmers here are highly experienced with 'gher' farming. A small river divides the village and the villagers reside on both sides of the river. From a total of 410 'gher' farmers living in the village, the survey selected 90 farmers in 2002 through applying a random sampling technique. The first round of survey was done covering a time span of six months (November 2001 to April 2002). The same cohort of farmers were interviewed for successive 12 years, and thus by allowing us to have a unique cohort of 90 'gher' farms for a 13-years making a balanced panel database of 1170 observations. It is worth mentioning here that as the 'ghers' are family owned, the ownership of the farms did not change, i.e. the farms are under the same household head. The first six rounds of surveys (i.e., 2002-08) were financed by Monbusho Doctoral Scholarship and subsequent JSPS Post-Doctoral Fellowship of the Government of Japan awarded to the second co-author. The later rounds of surveys (e.g. 2009-14) were supported by academic grants of that second co-author's employer in Bangladesh. The output and input variables used in the study are described below with their descriptive statistics presented in Table 1. A major concern with the DEA analysis is that, the frontier is sensitive to outliers and even a single outlier may shift the frontier to the highest level. We explored the data and did not find any statistically valid outlier in the database. But one may be suspicious to see higher standard deviations in the Table 1. This is because for better understanding of the farm level situations, we reported the average values estimated at per farm level, whereas the values become significantly lower when converted to per ha. Therefore, there is no issue of outlier that may affect DEA estimates.

Variables	Definition and measurements
Outputs	Four types of outputs were identified for calculating TFP:
Y1 = Prawns	Revenue from freshwater prawn (BDT at constant 2006 prices[2]).
Y2 = Carps	Revenue from carps (BDT at constant 2006 prices)
Y3 = HYV rice	Total amount of rice produced (kg)
Y4 = Straw	Total value of paddy straw (BDT at constant 2006 prices)
Inputs	Ten categories of inputs were used for calculating TFP:
X1 = Land area	Sum total of 'gher' area and HYV rice area within the 'gher' area (ha). We have aggregated these two areas because production of three enterprises takes place in cycles, as described in Section 2.
X2 = Land preparation	'gher' needs to be constructed or repaired every year. Sum total cost of 'gher' preparation and land preparation for cultivation of rice (BDT at 2006 constant prices).
X3 = paddy seedlings	Total cost of paddy seedlings (BDT at 2006 constant prices)
X4 = Irrigation	Total cost of supplementary irrigation (BDT at constant 2006 prices)
X5 = Nutrient	Sum total of active ingredient of all types of fertilizers, i.e., N, P, K, and Zn (kg)
X6 = Machine	Total cost of machines used for 'gher' and paddy field (BDT at constant 2006 prices)
X7 = Chemicals	Total cost of all pesticides, lime, potash alam, copper and rotanon (BDT at constant 2006 prices).
X8 = Labour	Total labour used in 'gher' which includes both family supplied and hired ones, (person days)
X9 = Fingerlings	Total cost of prawn and carp fingerlings (BDT at constant 2006 prices)
X10 = Feed	Total cost of all types of feed (BDT at constant 2006 prices). This includes broken and flat rice, eggs, vermicelli, wheat bran, fishmeal, snails, oilcakes and pulses.
Socio-economic determinants	Seven variables representing farmer's socio-economic characteristics were used as determinants of TFP and efficiency components:
D1 = Experience	Farmer's age as proxy for farming experiences (Years)
D2 = Education	Completed year of schooling of the farmer (Years)
D3 = Subsistence pressure	Total number of persons per household used as proxy for subsistence pressure (Number)
D4 = 'Gher' area	Total area of the 'gher' (ha)
D5 = Tenancy	Proportion of total 'gher' area rented in (%)
D6 = Share of family labour	Ratio of family labour and total labour (%)
D7 = Share of female labour	Ratio of female labour to total labour (%)

To summarise, four distinct outputs (prawns, carps, HYV rice and straw) and ten distinct inputs (land area, land preparation, paddy seedlings, irrigation, nutrient, machine, chemicals, labour,

[2] All current prices of inputs and outputs included in this study were converted to constant 2006 prices using national income deflator of Bangladesh. Therefore, any changes in values reflect real change net of the influence of inflation and/or any other factors.

fingerlings and feed) were used to represent the production technology and to compute productivity indices by applying Equation 14 while aggregation of outputs and inputs were done using Equations 15 and 16, respectively. In other words, the data were analysed in their most disaggregated form thereby allowing for reliable multitemporal (13 years) and multilateral (90 'gher' farms) comparisons of productivity and efficiency, unlike any previous studies of the 'gher' farming system.

5. Total Factor Productivity growth in 'gher' farming system

The estimated mean levels and changes in TFP indices and associated efficiency measures of the 90 'gher' farmers covering a 13-year period 2002–2014 are presented in Tables 2 and 3 and their trends are presented in Figures 2 and 3, respectively. The average TFP level is estimated at 0.71, technical efficiency level at 0.97, scale efficiency at 0.99, mix efficiency at 0.98, residual-scale efficiency at 0.86 and residual-mix efficiency at 0.85 (Table 2). The estimated efficiency scores imply that the 'gher' farmers are performing very well with respect to all measures of efficiency. The estimated technical efficiency levels are similar/higher than those reported for floodplain aquaculture in Bangladesh (scores ranging from 0.77–0.96 under different measures) and fish farms in Ghana estimated at 0.74, respectively (Bayazid et al., 2019; Onumah et al., 2018). The scale efficiency and mix efficiency levels showed relatively stable patterns, whereas TFP, residual-scale efficiency and residual-mix efficiency levels were fluctuating more over time (Figure 1).

[Insert Figure 2 and Table 2 here]

Overall, TFP grew annually @ 0.86%, which is highly encouraging because such positive trend persisted for 13 years at the farm-level (Table 3). This estimated TFP growth rate of 'gher' farming is much higher than the long-term (1948–2008) TFP growth rate of Bangladesh agriculture estimated at 0.57% p.a. (Rahman and Salim, 2013).

The estimated growth in TFP is fuelled by technical change increasing @ 0.54% p.a.

(Table 3). The prominent role of technical change was also noted in earlier literature (e.g. Rahman and Salim, 2013; Coelli *et al*., 2003 and Rahman, 2007). However, the observed TFP growth is supressed by consistently declining technical efficiency change @ 0.17% p.a. and scale efficiency change @ 0.10% p.a. Nevertheless, the mix efficiency change grew by @ 0.06% p.a. (Table 3). This implies that although 'gher' farmers have a declining technical efficiency level and operating at a sub-optimal scale but they are able to improve mix-efficiency change in order to reap the benefits of economies of scope by altering input and output mixes towards optimal level over time. The result here contradicts with Rahman and Salim (2013) who reported negligible growth of technical efficiency change @ 0.01% p.a., negligible decline of scale efficiency change @ 0.01% p.a. but higher reduction in mix efficiency change @ 0.19% p.a. for Bangladesh agriculture. Changes showed more fluctuating patterns for indices except technical change, mix efficiency change, and scale efficiency change (Figure 3).

[Insert Figure 2 and Table 3 here]

6. Drivers of TFP growth and its components

We develop the random effect Tobit model for panel data to determine the factors influencing TFP growth and its associated components. The model accounts for both farm specific systematic and time-varying effects created by the exogenous factors.

The econometric model capturing panel-level random effects with linearity assumption can be written as:

$$y_{it} = \boldsymbol{\beta X}_{it}^{'} + v_i + \varepsilon_{it} \qquad (17)$$

where y_{it} is the TFP change index and/or its components (k = 1, 2, …5); X is the matrix of explanatory variables, βs are the parameters to be estimated, v_i is the unit specific random element which is distributed as *IID,* N (0, σ_v^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) independent of the v_i. The observed data, y_{it}^0 can be censored in nature. When it is left-censored, we know $y_{it} \leq y_{it}^0$. Alternatively, when right-censored, we only observe $y_{it} \geq y_{it}^0$. When y_{it} is uncensored, $y_{it} = y_{it}^0$ (Statacorp, 2007).

Based on insights from existing literature, we have used seven variables to represent socio-economic status of the farmers. These are, farmer's experience and education, subsistence pressure, 'gher' operation area, tenancy, share of family supplied labour and share of female labour (includes both family supplied and hired). The background for inclusion of these variables is discussed below.

In Bangladesh, ownership of land represents a major source of wealth, which has significant role in crop choice and production decisions (Hossain et al., 1990). Toufique (2001) reported positive size-productivity relationship in technologically progressive areas, whereas the classic inverse correlation prevails in technologically backward areas. Also, literature reports that 'gher' area influences total production and smaller 'ghers' produce more (e.g. Islam et al., 2005). Therefore, 'gher' operation area is included to test whether operation size influences TFP growth and/or its components over time.

Education as a crucial technical efficiency enhancer variable is frequently seen in the literature (e.g., Rahman et al., 2011; Asadullah and Rahman, 2009). Education enables not only farmers' access to information, but also enhances their ability to comprehend the production related technical aspects, which will ultimately contribute towards higher technical efficiency (Rahman et al., 2011). Age as a proxy of experience and wisdom is included in the model as the aged farmers are hypothesized to make wiser decisions to ensure effective allocation and the use of scarce resources (e.g., Rahman, 2010). Hence, both education and age of the famers were included to identify their individual influence on TFP growth and/or its components.

Adoption of new technology can be a strategy for the farmers with higher subsistence pressure (Hossain et al., 1990) and therefore family size was incorporated to examine whether it affects TFP growth and/or its components. Rahman and Rahman (2008) noted that family supplied labour increases efficiency in rice production in Bangladesh. Similarly, Rahman

(2010) noted that in Bangladesh agriculture, female labour has a significant productivity and technical efficiency enhancement role, although the commonly held view is that women are mostly involved with post-harvest activities. In fact, the share of female labour in 'gher' farming is estimated at 23% of total labour use, which is substantial (Table 1). Therefore, both the shares of family labour and female labour were incorporated to know whether they independently contribute towards TFP growth and/or its components.

Table 4 presents Tobit elasticities along with the model diagnostics derived through estimating Eq. (17). The sources of variations are the parameters σ_u and σ_ε, where the former arises from the heterogeneity that exists farmers and the other is the idiosyncratic errors. The estimated rho (ρ) tells the intraclass correlation or the fraction of variance resulting from u_i. The estimated low values of these errors (σ_u and σ_ε) except for the value of ρ argues that very little variation in TFP change and its components is due to errors. Rather, the Wald χ^2 statistics confirms that the variations are mainly due to the seven socio-economic factors incorporated in the regression (bottom part of Table 4).

Experience of the farmer significantly improves TFP growth, technical change and mix efficiency change but reduces technical efficiency change and scale efficiency change in 'gher' farming (Table 4). The level of influence is highest on TFP growth, elasticity value 0.23. The implication is that although experienced farmers are able to adopt improve technologies and economies of scope by optimally mixing inputs and outputs, but they fail to maintain high level of technical and scale efficiencies over time. The failure to maintain or improve technical efficiency over time may be due to the influence of weather adversity and other factors (e.g., quality of feed, nutrients and chemicals) affecting productivity despite using given level of inputs. The failure to maintain scale efficiency over time may be due to limited opportunity to vary 'gher' operation size every year to optimal level which requires substantial construction and maintenance costs unlike conventional rice field. In contrast, Alam et al. (2014) reported significant adverse role of experience on the indices of TFP, technical efficiency and scale efficiency changes in Bangladeshi paddy farms, which is based on three rounds of a cohort of 73 rice farmers for the year 1988, 2000 and 2004. Onumah et al. (2018) also reported negative impact of farmers' experience on technical efficiency of fish farms in Ghana. In contrast, cross-section studies reported positive association between technical efficiency and farmer's experience (e.g. Herdt and Mandac, 1981; Kaliranjan, 1984; Rahman, 2003).

Education of the farmer significantly improves TFP growth and technical change as expected but reduces technical efficiency change (Table 4). The implication is that the educated farmers are better able to adopt improved technologies and increase TFP but are unable to maintain or improve technical efficiency over time which may be due to the effect of external factors, such as weather adversities and quality of inputs affecting productivity despite given level of input use. It is generally argued that, education positively contributes in farming efficiency (e.g. Ali and Flinn, 1989; Asadullah and Rahman, 2009), though some also did not find any significant impact of education on efficiency in Bangladesh agriculture (e.g. Wadud and White, 2000; Coelli et al., 2002). Rahman and Salim (2013) reported significant and positive role of education on technical change and negative influence on technical efficiency change in Bangladesh agriculture. But they also reported significant negative role of education on TFP growth which is at contrast with our findings. Similarly, Alam et al. (2014) noted significantly negative effect of education on the indices of TFP, technical change and technical efficiency change in Bangladeshi paddy farms. In contrast, Onumah et al. (2018) noted significantly positive impact of education on fish farming in Ghana.

Subsistence pressure significantly negatively influence technical change only. The implication is that the larger families are unable to improve technologies in 'gher' farming, which may be due to lack of investments. In contrast, Alam et al. (2014) observed family size significantly and positively influence indices of TFP, technical progress and technical efficiency change in paddy farms in Bangladesh. The reason may be that not all available working members from the family possess the type of skills required to operate such an integrated 'gher' farming system.

'Gher' operation size contributes towards technical efficiency improvements and TFP growth. This is in line with the dominant role of farm size in production, productivity and efficiency observed in land scarce countries (Lau and Yotopulos, 1971; Cornia, 1985) including Bangladesh (Rahman, 2003; Anik et al., 2017). The influence is highest on TFP growth, elasticity value estimated at 0.04. Both Alam et al. (2014) and Rahman and Salim (2013) reported positive contribution of average farm size on technical efficiency change and TFP growth in rice farming and overall Bangladesh agriculture, respectively. Onumah et al. (2018) also noted positive influence of pond area on technical efficiency of fish farms in Ghana.

'Gher' farms operated by tenant farmers also significantly improve technical change and TFP growth. The implication is that the tenant farmers are adopting improved technologies in 'gher' farming and able to improve TFP. In contrast, Alam et al. (2014) noted significantly negative influence of tenancy on the indices of TFP, technical change and technical efficiency change in paddy farms in Bangladesh. Barmon (2004) estimated that land rent for 'gher' farming is two times higher than conventional rice farming because of significantly higher income derived from this integrated farming system. Such high land rent compels tenants to adopt improved technology and be more efficient so that they can maintain profit from rented-in land. Majumder et al. (2009) reported that in Boro rice farming, tenants paying fixed-rate in advance are more efficient than owner-operators which conforms to our findings.

The use of family labour significantly improves technical progress and mix-efficiency change but reduces scale efficiency change. The implication is that the use of family labour enables farmers to adopt improved technologies, which ultimately helps them in deriving economies of scope by optimizing input-output mix but unable to improve scale efficiency which requires substantial investment to vary operation size over time. Rahman and Rahman (2008) observed significantly positive role of family labour on technical efficiency level in rice farms of Bangladesh (using a cross-sectional survey data) because of timely availability of labour input during peak times when hired labour may not be available. However, use of female labour (family supplied or hired) significantly reduces technical efficiency change, implying that female labour fails to maintain or improve technical efficiency in 'gher' farming. This finding contradicts with Rahman et al, (2011) and Rahman (2010) who noted significant positive role of female labour on productivity and technical efficiency in 'gher' farming and crop agriculture in Bangladesh, respectively using cross-sectional farm level data.

[Insert Table 4 here]

7. Conclusions and policy implications

The major motivation for this research was to investigate long-term productivity performance of 'gher' farms and identify their drivers using a cohort of 90 'ghers' over a 13-year period (2002–2014) which is non-existent in the literature.

The main conclusion drawn from this research is that the productivity of 'gher' farming system has improved over time and its growth rate is even faster than that of overall Bangladesh agriculture. TFP growth is mainly fuelled by technical change and mix-efficiency change. The growth rate of TFP took off from 2007 onward, peaked in 2009 and then reduced slightly with some fluctuation over time. Same pattern of change was also observed for the technical change component. Although no major structural change occurred in 'gher' farming practice because farmers are still following low-intensive traditional methods of prawn production, there has been gradual progress in production technology, such as, increasing use of commercial feed in addition to home-supplied feed and chemicals to prevent diseases in order to boost prawn output. These changes in production technology and input mixes led to increasing growth in TFP with less fluctuation over time from 2007 onward. In other words, 'gher' farming system is sustainable and holds great promise to foster growth of the broader agricultural sector and should be promoted with appropriate and targeted policy support, which in turn will boost farm income as well as export earnings for Bangladesh.

The following policies can be proposed from this study. First, government should invest in land and tenurial reforms to increase average operation size of ‘ghers’ through well-functioning land rental market as well as effective regulation and implementation of existing tenancy acts and laws which will synergistically increase TFP growth and improve technical change. This is in line with Alam et al. (2014) and Rahman and Salim (2013) who highlighted the importance of land reform measures to consolidate farm size in Bangladesh. The average farm size in the country is shrinking gradually and has reduced to nearly one-third from its 1960 level of 1.40 ha (Rahman and Salim, 2013). The average operating area of the surveyed ‘ghers’ is 0.88 ha (Table 1) which is 0.28 ha or 46.67% higher than the estimated national average of 0.60 ha (Rahman and Salim, 2013). But land consolidation to increase ‘gher’ operation size might be challenging due to socio-political, religious, cultural and economic reasons, particularly in densely populated countries where inheritance of paternal property right exists and off-farm income generating opportunities are limited (Parikh and Nagarajan, 2004; Jha et al., 2005; Niroula and Thapa, 2005, 2007).Second, investment in education for ‘gher’ farmers is needed as this will significantly improve TFP growth and technical change. Asadullah and Rahman (2009) also noted productivity and efficiency enhancing role of education in rice farming in Bangladesh and recommended investments in education. Finally, investment in education and training for female labourers to improve their skills is recommended so that they can contribute positively towards productivity and efficiency enhancement in ‘gher’ farming. It is noteworthy to mention that although girls’ enrolment in both primary and secondary education are higher than boys due to initiatives and policies undertaken by the government in the form of preventing child marriage and provision of stipends and fee waivers for girls in schools (Arends-Kuenning and Amin, 2004; BBS, 2017), but the literacy rate of women in the country is still lower than that of men (BBS, 2017). Therefore, in addition to education, training for women in the form of Farmers' Field School and other successful training models adapted in the country should be prioritized.

The implementation of these measures are formidable but improving long-term productivity of the joint 'prawn-carp-rice' farming in 'gher' system will significantly contribute towards growth and sustainability of the broader agricultural sector, farmers' income as well as the nation through export earnings, which is a goal worth pursuing.

References

Ahmed, N., Demaine, H., Muir, J.F., 2008. Freshwater prawn farming in Bangladesh: history, present status and future prospects. Aquaculture Research, 39(8), 806-819.

Ahmed, N., Flaherty, M.S., 2013. Opportunities and challenges for the development of prawn farming with fish and rice in southeast Bangladesh: potential for food security and economic growth. Food Security, 5, 637-649.

Alam, M.J., Begum, I.A., Rahman, S., Huylenbroeck, G.V., 2014. Tracing the impact of market reform on productivity growth of rice at the farm-Level in Bangladesh. Journal of the Asia Pacific Economy. 19, 391-408.

Al-Amin, A.Q. and Alam, G.M. (2016). Sustainability Challenges to Giant Freshwater Prawn (GFP) Firming Sector in Bangladesh: Lesson to Ensure Sustainable Economic Growth, Asian Journal of Agricultural, Research, 10(3-4):132-143.

Ali, M., Flinn, J.C., 1989. Profit efficiency among Basmati rice producers in Pakistan Punjab. American Journal of Agricultural Economics 71(2), 303–310.

Anik, A.R., Rahman, S., Sarker, J.R., 2017. Agricultural Productivity Growth and the Role of Capital in South Asia (1980–2013). Sustainability 9 (3), 470.

Arends-Kuenning, M., & Amin, S. (2004). School incentive programs and children’s activities: The case of Bangladesh. Comparative Education Review, 48(3), 295-317.

Asadullah, M.N., Rahman, S., 2009. Farm productivity and efficiency in rural Bangladesh: the role of education revisited. Applied Economics, 41, 17–33.

Barmon, B. K. (2004). Impacts of Rice-prawn Gher Farming on Land Tenure System in Bangladesh-A Case Study of Khulna District. Bangladesh Journal of Agricultural Economics, 27(2), 1-12.

Bayazid, Y., Umetsu, C., Hamasaki, H., Miyanishi, T. 2019. Measuring the efficiency of collective floodplain aquaculture of Bangladesh using Data Envelopment Analysis.

Aquaculture, 503, 537–549.

BBS, 2011. Bangladesh Labour Force Survey 2011. Statistics Division, Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh, Agargaon, Dhaka.

BBS, 2017. Education Scenario in Bangladesh: Gender Perspective. Statistics Division, Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh, Agargaon, Dhaka.

Bush, S.R., van Zwieten, P.A.M., Visser, L., van Dijk, H., Bosma, R., de Boer, W.F., Verdegem, M., 2010. Scenarios for resilient shrimp aquaculture in tropical coastal areas. Ecol. Soc. 15 (2), 15.

Chandra K. J., Chowdhury A. R. and D. R. Das, (2010), Shrimp culture practices at farmer's level in Bagerhat District, Progressive Agriculture. 21(1 & 2): 173–185.

Coelli, T, Rahman, S., Thirtle, C., 2003. A stochastic frontier approach to total factor productivity measurement in Bangladesh crop agriculture, 1961–92. Journal of International Development, 15, 321–333.

Coelli, T.J., Rahman, S., Thirtle, C., 2002. Technical, Allocative, Cost and Scale Efficiencies in Bangladesh Rice Cultivation: A Non-Parametric Approach. Journal of Agricultural Economics 53(3), 607–626.

Cornia, G.A., 1985. Farm size, land yields and the agricultural production function: An analysis for fifteen developing countries. World Development, 13(4), 513-534.

Csavas, I., 1993 Aquaculture development and environmental issues in the developing countries of Asia. In: Environment and Aquaculture in Developing Countries, ICLARM Conference Proceedings, Vol. 31 (ed. by R.S.V. Pullin, H. Rosenthal & J.L. Maclean), pp. 74-101. International Centre for Living Aquatic Resources Management (ICLARM), Manila, Philippines.

DoF, 2012. National fish week 2012 compendium (in Bengali). Department of Fisheries, Dhaka, Bangladesh.

Fan, S., Hazell, P., Thorat, S., 2000. Government spending, growth and poverty in rural India. American Journal of Agricultural Economics, 82, 1038-1051.

FAO, 2018. The State of World Fisheries and Aquaculture 2018. Food and Agriculture Organization of the United Nations, Rome.

FRSS., 2017. Fisheries statistical yearbook of Bangladesh 2016-17 (Vol. 34). Fisheries Resources Survey System (FRSS), Department of Fisheries. Dhaka, Bangladesh.

Hossain, M., Quasem, M.A., Akash, M.M. Jabbar, M.A., 1990, Differential impact of modern rice technology: The Bangladesh case. Bangladesh Institute of Development Studies, Dhaka, Bangladesh.

Islam, M.S., Milstein, A., Wahab, M.A., Kamal, A.H.M., Dewan, A.H.M., 2005. Production and economic return of shrimp aquaculture in coastal ponds of different sizes and with different management regimes. Aquaculture International, **13**, 489-500.

Ito, S., 2004. Globalization and agrarian change: a case of freshwater prawn farming in Bangladesh. Journal of International Development, 16,1003–1013.

Jha, R., Nagarajan, H.K., Prasanna, S., 2005. Land fragmentation and its implications for productivity: evidence from Southern India. Working Paper. Australia South Asia Research Centre, Canberra, Australia.

Kamp, K., Brand, E., 1994. Greater options for local development through aquaculture (GOLDA). CARE–GOLDA Project, Dhaka, Bangladesh.

Kendrick, A., 1994. The gher revolution: the social impacts of technological change in freshwater prawn cultivation in southern Bangladesh. Bangladesh Aquaculture and Fisheries Resource Unit, Dhaka, Bangladesh.

Lau, L., Yotopulos, P., 1971., A test for relative efficiency and application to Indian agriculture. The American Economic Review, 61(1), 94-109.

Le Clech, N. A., and C. F. Castejón. 2017. "Productivity, efficiency and technical change in world agriculture: aFäre-Primont index approach."Documentos de Trabajo dt2017-09, Facultad de Ciencias Económicasy Empresariales, Universidad de Zaragoza.

Majumder, M. K., Mozumdar, L., & Roy, P. C. (2009). Productivity and resource use efficiency of Boro rice production. Journal of the Bangladesh Agricultural University, 7(2), 247-252.

MoF, (2018). Bangladesh Economic Review2018, Economic Adviser's Wing, Finance Division, Ministry of Finance, Government of the People's Republic of Bangladesh, Tejgaon, Dhaka.

Movik, S., Mehta, L., Mtisi, S., Nicol, A., 2005. A blue revolution for African agriculture? International Development Studies Bulletin, 36,41–45.

Mukherjee, A.N., Kuroda, Y., 2003. Productivity growth in Indian agriculture: is there evidence of convergence across states? Agricultural Economics, 29, 43-53.

Niroula, G.S., Thapa, G.B., 2005. Impacts and causes of land fragmentation, and lessons learned from land consolidation in South Asia. Land Use Policy 22, 358–372.

Niroula, G.S., Thapa, G.B., 2007. Impact of land fragmentation on input use, crop yield and production efficiency in the mountains of Nepal. Land Degradation and Development 18, 237–248.

O'Donnell, C.J., 2010. Measuring and decomposing agricultural productivity and profitability change. Australian Journal of Agricultural and Resource Economics, 54, 527-560.

O'Donnell, C.J., 2011a. DPIN 3.0. A program for decomposing productivity index numbers. Centre for Efficiency and Productivity Analysis, University of Queensland, Brisbane, Australia.

O'Donnell, C.J., 2011b. The sources of productivity change in the manufacturing sectors of the US economy, Centre for efficiency and productivity analysis (CEPA) working paper, No

WP07/2011, University of Queensland, Australia.

O'Donnell, C.J., 2012a. Nonparametric estimates of the components of productivity and profitability change in US agriculture. American Journal of Agricultural Economics, 94, 873-890.

O'Donnell, C.J., 2012b. An aggregate quantity-price framework for measuring and decomposing productivity and profitability change, Journal of Productivity Analysis, doi: 10.1007/s11123-012-0275-1.

Onumah, E.E., Onumah, J.A., Onumah, G.E. 2018. Production risk and technical efficiency of fish farms in Ghana. Aquaculture, 495, 55–61.

Parikh, K., Nagarajan, H.K., 2004. How important is land consolidation? Land frag-mentation and implications for productivity: case study of village Nelpathur in Tamil Nadu. Occasional Paper. Department of Economic Analysis and Research, NABARD, India.

P.C., 2009. Steps Towards Change – National Strategy for Accelerated Poverty Reduction II (Revised). FY 2009-11. Planning Commission of the Government of the People's Republic of Bangladesh, Dhaka.

Pàez-Osuna, F., 2001. The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives. Environmental Management 28, 131–140.

Phillips, M.J., Lin C.K., Beveridge M.C.M., 1993. Shrimp culture and the environment: lesion from the world's most rapidly expanding warm water aquaculture sector. In: Environment and Aquaculture in Developing Countries, ICLARM Conference Proceedings, Vol. 31 (ed. by R.S.V. Pullin, H. Rosenthal & J.L. Maclean), pp.171-197. International Centre for Living Aquatic Resources Management (ICLARM), Manila, Philippines.

Primavera, J.H., 1997. Socio-economic impacts of shrimp culture. Aquaculture Research 28, 815–827.

Rahman, S., 2003. Profit efficiency among Bangladeshi rice farmers. Food Policy, 28(5-6), 487–504.

Rahman, S., 2007. Regional productivity and convergence in Bangladesh agriculture. Journal of Developing Areas, 41, 221-236.

Rahman, S., 2010. Women's labour contribution to productivity and efficiency in agriculture: empirical evidence from Bangladesh. Journal of Agricultural Economics, 61, 318-342.

Rahman, S., Barmon, B.K. 2012. Energy productivity and efficiency of the 'gher' (prawn-fish-rice) farming system in Bangladesh. Energy. 43, 293-300.

Rahman, S., Barmon, B.K., Ahmed, N., 2011. Diversification economies and efficiencies in a 'Blue-Green Revolution' combination: a case study of prawn-carp-rice farming in the 'gher' system in Bangladesh. Aquaculture International, 19, 665-682.

Rahman, S., Rahman, M., 2008. Impact of land fragmentation and resource ownership on productivity and efficiency: the case of rice producers in Bangladesh, Land Use Policy: 26, 95–103.

Rahman, S., Salim, R., 2013. Six decades of total factor productivity change and sources of growth in Bangladesh agriculture (1948-2008). Journal of Agricultural Economics. 64, 275-294.

Rashid, M.H.A., Chen, J-R., 2002. Technical efficiency of shrimp farmers in Bangladesh: a stochastic frontier production function analysis. Bangladesh Journal of Agricultural Economics, 25, 15-31.

Shang, Y.C., Leung, P.S., Ling, B-H., 1998. Comparative economics of shrimp farming in Asia. Aquaculture, 164, 183-200.

Stata Corp, 2007. Stata Version 10. Stata Press Publications, College Station, Texas, USA.

Thangadurai, A. J. 1991. Experimental culture of freshwater prawn (*Macrobrachium rosenbergii*) in ponds. In: Proceedings of National Symposium on New Horizons in Freshwater Aquaculture. Central Institute of Freshwater Aquaculture, Bhubaneswar, Orissa, India. pp. 7-8.

Toufique, K.A., 2001. Structural constraint to agricultural growth: an explanation of the farm size productivity relationship in Bangladesh. Working Paper. Bangladesh Institute of Development Studies, Dhaka.

Wadud, A., White, B., 2000. Farm Household Efficiency in Bangladesh: A Comparison of Stochastic Frontier and DEA Methods. Applied Economics 32, 1665–1673.

Table 1. Descriptive statistics of the variables per farm

Variables	Unit	Mean	Standard deviation	Median	Minimum	Maximum
Outputs						
Y1 = Prawns	BDT	336725.76	314345.53	246775.95	59238.36	2740511.60
Y2 = Carps	BDT	19943.45	15160.72	15863.33	2051.55	76920.15
Y3 = HYV rice	kg	2594.21	2259.30	2000.00	480.00	17800.00
Y4 = Straw	BDT	2591.27	2972.04	1754.08	375.18	26373.63
Inputs						
X1 = Land area	ha	0.88	0.71	0.67	0.20	4.81
X2 = Land preparation	BDT	11624.84	13997.80	6461.41	435.95	135000.00
X3 = Paddy seedlings	BDT	720.36	693.44	495.68	60.88	5769.97
X4 = Irrigation	BDT	890.54	1016.21	577.00	10.00	7931.67
X5 = Nutrient	kg	31.76	33.35	20.55	0.00	241.20
X6 = Machine	BDT	568.73	778.50	395.71	20.00	16938.39
X7 = Chemicals	BDT	2131.39	1804.71	1490.64	244.00	13510.00
X8 = Labour	Person day	474.25	227.12	422.00	169.00	1902.00
X9 = Fingerlings	BDT	45306.83	36899.09	35602.23	7825.00	277500.00
X10 = Feed	BDT	63958.08	70875.40	41828.01	1960.00	633327.69
Socio-economic determinants						
D1 = Experience	Year	42.94	14.33	42.00	16.00	82.00
D2 = Education	Year	6.34	3.67	9.00	0.00	15.00
D3 = Subsistence pressure	Number	4.23	1.01	4.00	2.00	7.00
D4 = 'gher' area	ha	0.54	0.43	0.67	0.55	2.80
D5 = Tenancy	Percent	0.41	0.43	0.26	0.00	1.00
D6 = Share of family labour	Percent	0.38	0.22	0.36	0.02	1.00
D7 = Share of female labour	Percent	0.23	0.12	0.22	0.00	0.60
Total number of observations	Number	1170				

Table 2. TFP and efficiency levels

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)
2002	0.8234	0.9881	0.9950	0.9725	0.8311	0.8123	0.6576
2003	0.8568	0.9825	0.9902	0.9687	0.8421	0.8238	0.6868
2004	0.8568	0.9780	0.9921	0.9787	0.8219	0.8108	0.6740
2005	0.8674	0.9796	0.9848	0.9810	0.8553	0.8519	0.7129
2006	0.8674	0.9649	0.9887	0.9769	0.8419	0.8319	0.6883
2007	0.8674	0.9813	0.9905	0.9807	0.8566	0.8482	0.7151
2008	0.8674	0.9609	0.9826	0.9700	0.8751	0.8638	0.7074
2009	0.8674	0.9684	0.9877	0.9753	0.9044	0.8930	0.7409
2010	0.8780	0.9809	0.9899	0.9801	0.8753	0.8666	0.7389
2011	0.8780	0.9692	0.9838	0.9772	0.8660	0.8601	0.7202
2012	0.8780	0.9652	0.9812	0.9745	0.8704	0.8645	0.7188
2013	0.8780	0.9751	0.9866	0.9780	0.8562	0.8488	0.7170
2014	0.8780	0.9677	0.9836	0.9799	0.8704	0.8672	0.7247
Geomean	0.8663	0.9739	0.9874	0.9764	0.8587	0.8492	0.7075

Table 3. TFP change and its components

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
2002	1.0406	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2003	1.0406	0.9944	0.9952	0.9961	1.0133	1.0142	1.0443
2004	1.0534	0.9898	0.9971	1.0064	0.9889	0.9981	1.0250
2005	1.0534	0.9914	0.9897	1.0087	1.0291	1.0487	1.0841
2006	1.0534	0.9765	0.9936	1.0044	1.0130	1.0240	1.0467
2007	1.0534	0.9932	0.9954	1.0084	1.0307	1.0441	1.0874
2008	1.0534	0.9725	0.9875	0.9973	1.0529	1.0634	1.0758
2009	1.0664	0.9801	0.9927	1.0028	1.0882	1.0993	1.1267
2010	1.0664	0.9928	0.9949	1.0077	1.0532	1.0668	1.1235
2011	1.0664	0.9810	0.9888	1.0048	1.0419	1.0588	1.0951
2012	1.0664	0.9769	0.9861	1.0020	1.0473	1.0642	1.0931
2013	1.0664	0.9869	0.9915	1.0056	1.0302	1.0449	1.0902
2014	1.0406	0.9794	0.9885	1.0076	1.0473	1.0675	1.1020
Growth rate (%)	0.5437	-0.1671	-0.0952	0.0645	0.4108	0.5738	0.8562

Table 4. Determinants of TFP change and its components

Variables	Tobit Elasticities				
	Technical change	Technical efficiency change	Scale efficiency change	Mix efficiency change	TFP change
Socio-economic factors					
Experience	0.0137***	-0.0205***	-0.0099**	0.0105*	0.2370***
Education	0.0030***	-0.0134**	0.0004	-0.0012	0.0520***
Subsistence pressure	-0.0050***	0.0009	0.0002	0.0020	-0.0081
‘Gher’ area	0.0006	0.0098**	-0.0006	0.0047	0.0478***
Tenancy	0.0010**	0.0011	-0.0008	0.0008	0.0240***
Share of family labour	0.0017*	0.0044	-0.0026**	0.0081**	0.0047
Share of female labour	0.0001	-0.0094***	-0.0038	-0.0025	0.0018
Model diagnostics					
σ_u	0.0001	0.0296***	0.0139***	0.0173***	0.0806***
σ_e	0.0170***	0.0326***	0.0180***	0.0269***	0.0515***
ρ	0.0001***	0.4517***	0.3757***	0.2931***	0.7103***
Wald χ^2 (7 d.f.)	78.2***	21.09***	11.93*	11.76*	166.15***
N	1170	1170	1170	1170	1170

Note: *** = significant at 1% level ($p<0.01$)
** = significant at 5% level ($p<0.05$)
* = significant at 10% level ($p<0.10$).

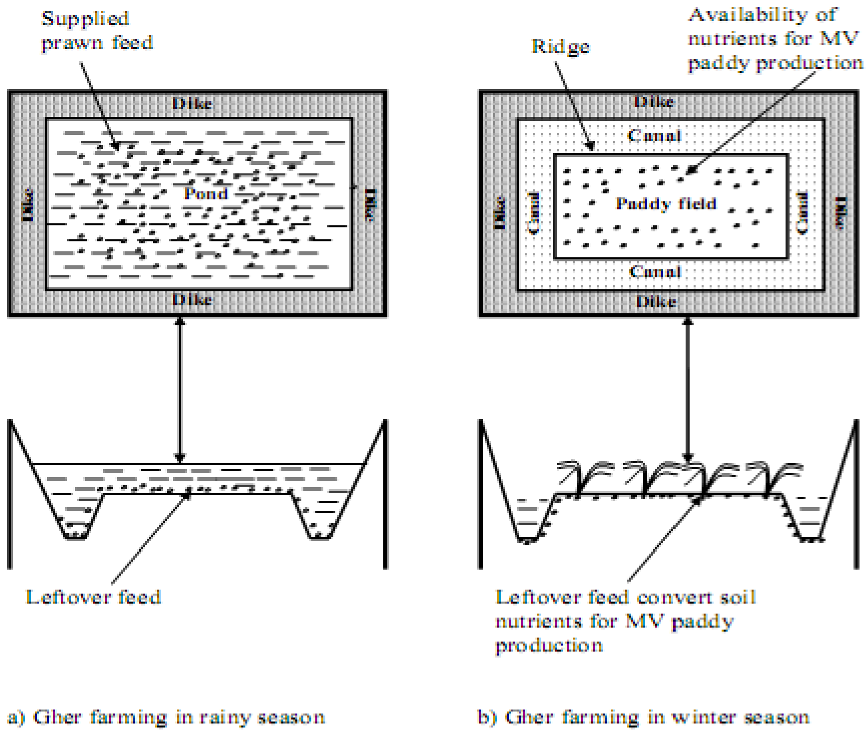

Figure 1. The ‘gher’ farming system

Source: Adapted from Barmon et al., 2008.

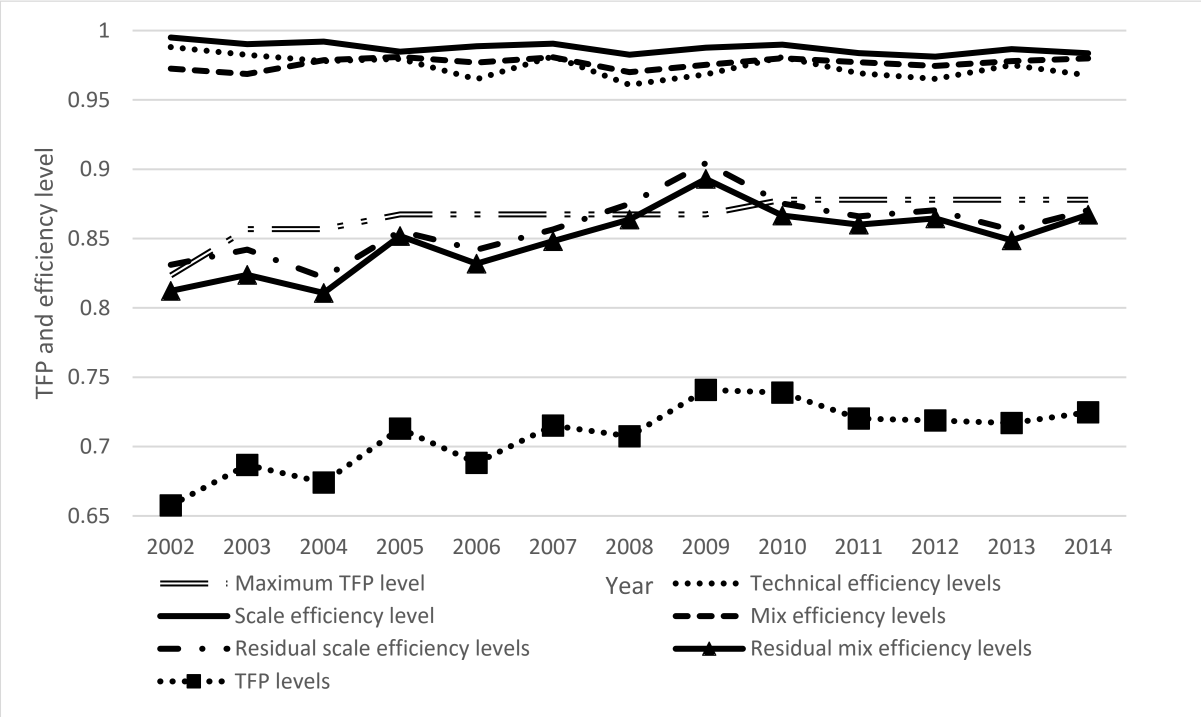

Figure 2. TFP and efficiency levels

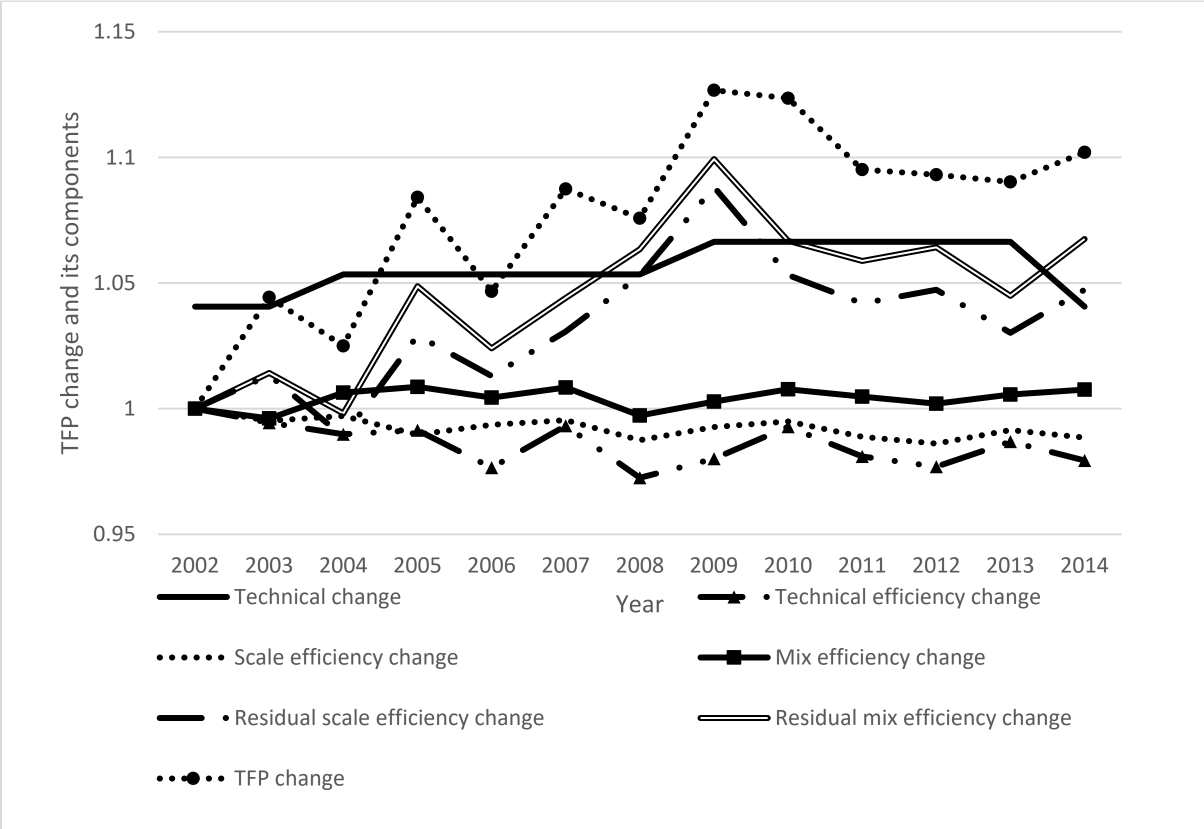

Figure 3. TFP change and its components