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Efficiency of Culture-based Fisheries Production in Village Irrigation Systems of Sri Lanka

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Abstract

Despite the growing popularity of culture-based fisheries (CBFs) associated with village irrigation systems (VISs) in Sri Lanka, there is little knowledge about factors that influence productivity levels. CBFs competes with rice for access to water in the VIS, so maximising the efficiency of CBFs is essential to ensure that the limited water resources are used most effectively. To redress this, primary data from 325 fish farming groups were used to estimate a stochastic translog production frontier. Technical efficiency in these irrigation systems was found to be generally low, and substantially lower than that of other aquaculture production systems in other Asian countries. This suggests that production can be increased substantially with better management using existing technology and resources. Removing subsidies, improving consultation with extension officials, and improving water user rights – in particular the introduction of a transferable community quota system – were found to be key means for improving efficiency.

Keywords: Village irrigations systems, culture-based fisheries, stochastic translog production frontier, technical efficiency, productivity.

JEL: Q22, D24, O12

INTRODUCTION

Global aquaculture is growing rapidly, with just over half (56% by value) of aquaculture production being produced in freshwater ponds and tanks (Bostock et al., 2010). Asia – the highest global consumer of freshwater fish - is the epicentre of aquaculture production. In Sri Lanka, the development of culture-based fisheries (CBFs) based on stocking fish fingerlings in village irrigation systems (VISs) has grown in popularity over the last three decades (Pushpalatha and Chandrasoma, 2010). The expansion of inland fisheries and aquaculture has been given a high priority in Sri Lanka because fish are a cheap source of animal protein for rural low income communities. Moreover, CBFs generate supplementary income for farmers and are a source of additional rural employment (Chakrabarty and Samaranayake, 1983, Pushpalatha and Chandrasoma, 2010) and food security. However, the contribution of the fisheries sector to Sri Lanka's GDP is relatively small (1.3% in 2016), contributing to around 10% of total employment and supports over 2.4 million livelihoods (Fisheries Statistics, 2017). In 2016, inland fisheries and aquaculture, contributed 14% to total fisheries production by volume (Fisheries Statistics, 2017).

The contribution of CBF to the Sri Lanka economy is less clear, as much of the production is aimed at providing local communities with fish for their consumption, with only some of these sold in the market. Much of this production has been opportunistic, taking advantage of the existence of the water resources temporarily available through the VIS.

The original development of VIS based CBFs in the 1980s was unsuccessful due to biological productivity-related problems such as the non-availability of effective means to select suitable reservoirs and lack of a guaranteed supply of fingerlings for stocking (De Silva, 2003). Weak institutional linkages, lack of legislation and poorly planned social mobilisation procedures also contributed to the unsustainability of CBFs. Although some of these constraints, especially at the grassroots level, have been dealt with through the concerted efforts of fishery biologists, barriers still exist. These are found at the institutional level - i.e., water allocations and water user rights – and in the provision of adequate infrastructure, communication and information.

A feature of the VIS based CBFs that distinguished it from many other types of aquaculture is that the pond infrastructure (i.e. the VIS) was primarily developed to provide irrigation water for rice production, and the fishery competes with rice production for access to sufficient water resources. Optimal allocation of water between the two competing users of the resource is determined by the marginal value product of water (MPV_w) to each. Retaining more water for CBF requires its MVP_w to increase relative to that of rice production. With fixed physical inputs (area of the VIS and water quantity), this can only occur through improving efficiency of the CBF production.

Studies of technical efficiency in aquaculture elsewhere have suggested that the choice of fish species, water management and feed management are critical for the optimal performance of fish production (Sharma and Leung, 2000b, Sharma and Leung, 2000a). In addition, intensification (Dey et al., 2005, Kareem et al., 2009, Sharma and Leung, 2000a), integrated rice-fish culture (Saikia and Das, 2008, Fernando, 1993, Iinuma et al., 1999) and efficient resource allocation (Alam and Murshed-e-Jahan, 2008, Phengphaengsy and Okudaraia, 2008) have also been found to be important determinants of productivity in some countries. Other studies have suggested that productivity is constrained by human capital such as education, experience and training (Kularatne, 2009, Kareem et al., 2009, Anh Ngoc et al., 2018, Zongli et al., 2017), basic infrastructure (roads), easy access to fingerlings, and security of property rights (Dey et al., 2000).

In some countries there is a well-defined system of property rights for aquaculture farmers (e.g., Nigeria) whereas Sri Lankan CBFs farmers use common pool water resources for CBF production. Rights for reservoir water use for agriculture and CBF are granted to farmers organisations (FOs) under the Agrarian Development Act of 2000. However, rights to water used for CBFs are not well-defined under current legislation. Notably, despite the enactments of the National Aquaculture Development Authority of Sri Lanka (NAQDA) Act of 1998 (Act 53) and its subsequent amendment in 2006 (Act No. 145), there are insufficient legal provisions to properly facilitate CBFs or aquaculture development in VISs. The quantity of water available for CBFs activities are largely determined by the volume of water use by rice farmers. This lack of property rights has created a number of problems for CBFs production, particularly that relating to the management of the fish stock, which is also effectively a common property resource.

Given these poorly defined property rights over both water and fish stocks, productivity is likely to be largely determined by the strength of the institutional arrangements established in each village. Where collective property rights are involved, larger groups have been found to be less likely to contribute to collective action than smaller groups (Oliver and Marwell, 1988). Additionally, the lack of dependence of Sri Lankan CBFs on supplementary fish feeding (De Silva, 2003) contrasts with the heavy dependence of aquaculture systems in other parts of the world. While pond size is adjustable in some countries reservoir size in Sri Lanka is fixed. The only means to increase reservoir water levels is to increase water user efficiency of other uses such as rice farming.

In this paper, we examine the technical efficiency (TE) and the factors influencing efficient use of village reservoir water for CBF. The paper is organised as follows. Section two provides a general introduction to VISs and briefly discusses CBFs development in Sri Lanka. In Section three the data and the estimated empirical models are discussed. Section four discusses the results and Section five discusses the policy implications for the improvement of technical efficiency (TE) and concludes.

BACKGROUND TO VIS AND CBF PRODUCTION IN SRI LANKA

Fishing is a major industry in Sri Lanka. While its contribution to GDP is relatively small (2.3% in 2005), fishing contributes to around 10% of total employment and supports over 2.4 million livelihoods (Department of Census and Statistics - Sri Lanka, No date). In 2004, inland fisheries and aquaculture, contributed 20% to total fisheries production by volume (Department of Census and Statistics - Sri Lanka, No date).

The contribution of CBF to the Sri Lanka economy is less clear, as much of the production is aimed at providing local communities with fish for their consumption, with only some of these sold in the market. Much of this production has been opportunistic, taking advantage of the existence of the water resources temporarily available through the VIS.

Development of the VIS

Over a period of two thousand years, a multitude of reservoirs have been constructed in Sri Lanka with the primary objective of irrigating paddy (rice) fields. The construction of these reservoirs has enabled rainfall to be widely distributed in low rainfall regions. These reservoirs represent about 75% of the inland water surface of the country (NSF, 2000). The reservoirs in Sri Lanka can be categorised into four main types based on their capacity and functions: (i) Large reservoirs used for hydroelectric power generation and irrigation constructed in the last 30 years, of which there are six; (ii) Ancient medium sized reservoirs mainly to provide irrigation and to a lesser extent power generation, of which there are 72; (iii) Minor perennial reservoirs, of which there are 160; and (iv) Minor non-perennial reservoirs, also referred to as Village Irrigation Systems (VISs), of which there are approximately 10,000 operational covering 23% (39,271 hectares) of the total surface of land water.

These VISs (minor non-perennial reservoirs) are less than 80 hectares in size and are managed by the respective FOs (DAD, 2000). They are distributed over the entire low rainfall regions of the country and depend entirely on direct monsoonal rainfall and runoff water from their own catchment areas. Hence, they are positioned where distinct cascades exist in well-defined small cascades or in meso-catchment basins (Panabokke, 2001). Since these VISs depend entirely on direct monsoonal rainfall, they are seasonal reservoirs where water levels fall very low or run dry during the dry season from August-September.

Development of CBFs

Although these VISs were originally created to irrigate paddy (rice) fields, rice production under VISs has been declining since 1977. This can partly be attributed to cheaper imports resulting in domestic producers receiving lower prices for their paddy output. With the decline of water used for paddy cultivation, these reservoirs have been increasingly used for fish production during the last three decades. The potential for these VISs to be used for CBFs was first pointed out by Mendis (1965). Since there initiation in the 1980s (Puspalatha and Chandrasoma, 2010), it has been shown that these VISs and other small-sized perennial reservoirs can be used to develop CBFs through stocking of hatchery-reared carp species and subsequent recapture after a growth period of approximately 7-9 months (Thayaparan, 1982; De Silva, 1988). Most (if not all) of these VISs depend on the inter-monsoonal rains in November–December for adequate water for CBF purposes, with the fish being harvested during the peak dry season in August–October. Hence, CBFs is highly seasonal in nature.

The CBF enhancement strategy (Lorenzen, 2001) is based on the use of a combination of Chinese and Indian major carp species - rohu, mrigal, common carp, bighead carp, silver carp and the exotic cichlid species [*Oreochromis niloticus* and *O. mossambicus*] (De Silva, 2003). Existing operational village reservoirs – of which there are more than 10,000 in Sri

Lanka - are stocked with fingerlings after the inter-monsoonal rainy season (December-January) and harvested during the dry season (August-September). In this way, these seasonal reservoirs become the highly productive core of CBFs (De Silva, et al., 2003; (Jayasinghe et al., 2005 (a)); 2005a; Amarasinghe & Nguyen, 2009).

The practices followed in Sri Lankan CBFs are considerably different to those in a number of other Asian countries. In Sri Lanka, CBFs techniques are similar to those used in extensive aquaculture carried out in man-made reservoirs, where ecological conditions are different from natural inland water bodies used for CBFs and aquaculture in other Asian localities (e.g., Oxbow lakes in Bangladesh, Taal Lake in the Philippines). However, in CBFs, there is no artificial or supplementary feeding system. In Sri Lanka, the government undertakes the main role of fingerling rearing and distribution through government owned breeding centres. This is in contrast to a number of other countries in the Asian region where private dealers dominate this sector.

Management of the VIS is undertaken by farmer organizations (FO) with an aquaculture committee given responsibility for managing CBF. Members of the aquaculture committee are self-selected, provide labor input, and share the resulting profits. An agreed proportion of the profit from the CBF is utilized for improvement of the reservoirs (e.g. strengthening of earthen bunds). Those FOs that do not have a “group” of farmers to conduct CBF activities permit a single farmer to perform CBF activities based on the same conditions that are set for a group of farmers.

METHODOLOGY

Model

The approach used involves the estimation of a stochastic production frontier with an explicit inefficiency model (Battese and Coelli, 1995), from which production elasticities and factors affecting the level of technical efficiency can be derived. Such an approach has been applied in both developed and developing countries to assess productivity in a wide range of industries (Bravo-Ureta and Pinheiro, 1993, Worthington, 2014). Developing country examples include studies in agriculture (Villano and Fleming, 2006, Kalirajan and Shand, 1986, Gedara et al., 2012), wild caught fisheries (Squires et al., 2003, Zen et al., 2002, Duy and Flaaten, 2016) and aquaculture (Singh et al., 2009, Iliyasu et al., 2014, Islam et al., 2014, Sharma and Leung, 2003, Kumaran et al., 2017, Iliyasu et al., 2016, Worthington, 2014, Iinuma et al., 1999).

A range of potential stochastic production frontier (SPF) functional forms exist, including the translog, Cobb-Douglas and constant elasticity of substitution (CES) forms, where the last two are effectively special cases of the translog. The translog production frontier (Aigner et al., 1977, Meeusen and Van den Broeck, 1977) is given by:

$$\ln y_i = \beta_0 + \sum_k \beta_k \ln x_{k,i} + 0.5 \sum_k \sum_l \beta_{k,l} \ln x_{k,i} \ln x_{l,i} - u_i + \varepsilon_i \qquad (1)$$

where y_i is the quantity of output produced by farm group i, x is a vector of inputs, u_i is a one sided error term ($u \geq 0$) representing the level of inefficiency of the farm group i and ε is a random error term. The TE of the i-*th* sample farm is given by $TE_i = exp\ (-u_i)$. Inefficiency is modeled explicitly as a function of known characteristics and exogenous effects, such that:

$$u_i = \delta_0 + \sum_j \delta_j Z_{ij} + w_i \qquad (2)$$

where Z is a set of $j = 1,\ldots,J$ firm-specific variables which may influence the firm's efficiency, δ_j is the associated inefficiency parameter coefficient, and w_i is an iid random error term (Battese and Coelli, 1995).

There is a trade-off between flexibility and theoretical consistency when using the translog functional form (Sauer et al., 2006, Sauer and Hockmann, 2005). Economic theory suggests that for profit maximization, the production function should be monotonically increasing and quasi-concave for all inputs (Lau, 1978). However, there is less need to impose the convexity constraints when estimating production frontiers since these are based on the assumption that producers aim to maximize output for a given set of inputs rather than profit maximization *per se*, and in which case only monotonicity is essential (Henningsen and Henning, 2009). Further, imposing global convexity also imposes undesirable restrictions on translog production functions, substantially reducing their flexibility (Lau, 1978, Sauer et al., 2006). However, non-convexity has implications for efficiency measures, so an ex post evaluation of convexity is important.

In this study, we have adopted a multistage process to ensure monotonicity is imposed (Henningsen and Henning, 2009). This involves first estimating the translog frontier and extracting the unrestricted parameters $\hat{\beta}$ and their covariance matrix $\hat{\sum}_{\beta}$. Second, we estimate the restricted $\hat{\beta}^0$ parameters through a minimum distance approach, given by:

$$\hat{\beta}^0 = \arg\min\left(\hat{\beta}^0 - \hat{\beta}\right)\hat{\Sigma}_{\beta}^{-1}\left(\hat{\beta}^0 - \hat{\beta}\right) \tag{3}$$

subject to:

$$\frac{\partial f(x,\beta^0)}{\partial x} \geq 0 \quad \forall i, x \tag{4}$$

This is solved using quadratic programming to find the revised set of coefficients $\hat{\beta}^0$ that conform to the monotonicity assumption. Finally, the stochastic frontier model is re-estimated as:

$$\ln y_i = \alpha_0 + \alpha_1 \ln \tilde{y} - v_i + \varepsilon_i \tag{5}$$

where $\tilde{y} = f(x, \hat{\beta}^0)$. That is, the only input is the estimated frontier output based on the restricted parameters. The parameters α_0 and α_1 represent final adjustments to the parameter estimates. Ideally, $\alpha_0 = 0$ and $\alpha_1 = 1$ as this indicates that the restricted model produces identical predictions as those produced by the unrestricted model (Henningsen and Henning, 2009). Since the data were normalized, such that $\ln(\bar{X}) = \ln(y) = 0$, the coefficient on the input levels directly relates to the elasticity at the mean input and output level.

DATA

Survey design and implementation

Primary data were used to analyze the TE effect on CBFs production. Kurunegala and Anuradhapura districts in Sri Lanka were selected as study areas since they have the highest number of reservoirs used for CBFs production. There are 10,094 village reservoirs currently being used for rice production in Sri Lanka, of which Kurunegala district has the highest number - 4,192. Anuradhapura district has the second highest with 2,333 VISs (De Silva et al., 2006). The two districts are adjacent to each other and, as such, are homogeneous in climate, vegetation and other social and economic aspects (Fernando, 1993).

A multi-stage cluster sampling method (Cochran, 1960) was used for sample selection. Each stage represented the number of reservoirs, based on an administrative hierarchy from national level to village level. Two districts (Kurunegala and Anuradhapura) were identified for stage 1 while the DSDs/Agrarian Development Divisions within each district formed the basis for stage 2. The third stage was based on CBFs active reservoirs within the Grama Niladhari Divisions[1]/villages. A group of fish farmers from each reservoir engaged in CBF production was considered as a sample unit for the survey as CBF is essentially a group activity.

As the CBF industry is not well established in all village reservoirs of Sri Lanka, CBF activities are not conducted annually. Therefore, CBF production data were collected during several culture cycles from 2006 to 2009. From Kurunegala and Anuradhapura districts, 334 reservoirs (165 and 169 respectively) where CBFs activities had been conducted during the fish culture year cycles were identified. This represented about 29% of the total reservoirs (1,168) used for CBF production in the country over the last three fish culture cycles. From the 334 reservoirs identified, data were collected from 325 (165 and 160 reservoirs) CBF farmer groups from Kurunegala and Anuradhapura districts respectively. Nine reservoirs in the Anuradhapura district were not sampled due to the unavailability of an adequate number of farmers in the village during the survey period.

Data were collected through face-to-face interviews in which CBF farmers were surveyed by means of group discussions. Due to the geographical distribution of the 325 village irrigation systems selected in the two districts and due to time constraints, the survey was undertaken with the assistance of Agricultural Development Officers (ADOs) and their assistants, who were trained over two stages. In stage 1, two special one-day workshops were organised for all ADOs of the Agrarian Services in Development Divisions (ASDDs) where CBF production was carried out during the last three fish culture cycles in the two districts. In these meetings, the purpose of the survey and the questionnaire were discussed comprehensively with the Divisional Officers. In stage 2, another two-day workshop was

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[1] Local government administrative unit.

organised by all ADOs in their ASDD for Agricultural Research and Production Assistants ARPAs working in the respective villages in the two districts. Similarly, in this meeting the purpose of the survey and the questionnaire were discussed in detail with ARPAs. The following day, ARPAs were trained to interview CBF farmers.

FO office bearers (president, secretary and treasury) and several other members of FOs were chosen for the group interviews. ARPAs worked as enumerators of the survey. Districts Agrarian Development Commissioners (DADC) from the two districts organised meetings with ADOs. DADC also helped organise and train ARPAs for the surveys in their divisions. All ARPAs corresponded with each other during the survey. The CBF farmer survey was completed in 4 months, during the period, December 2009 to March 2010.

Model inputs

The survey collected information on CBF output levels, input use and also characteristics of CBF farmers and reservoirs. The dependent variable used in the model (collected from the survey) was the level of CBF production (Y_i). Data on three key inputs was also collected (or subsequently derived): water (x_1), labor (x_2), and total fish fingerlings (x_3). In addition, information on farmer and reservoir specific characteristics (z) were collected and which were used in the inefficiency model. A description of variables used in the inefficiency model is provided in Table 1.

<Table 1 about here>

Summary statistics of the output and input variables together with various VISs and group-specific variables used in the analysis are shown in Table 2. All input and output data were log-normalized such that $\ln(\overline{x}_j) = \ln(\overline{y}) = 0$.

<Table 2 about here>

The volume of water used from individual reservoirs for CBF production is one of the key input variables used in the analysis. There is no definitive water measuring system for individual water users' under VISs. Reservoirs are distinguished by their size. The amount of water available for CBFs activities (w_{fi}) is given by $w_{fi} = C_{ri}(1 - R_i)$ where w_{fi} is the share of water used by the i-th reservoir for CBF production, C_{ri} is the ith reservoir capacity at the full supply level and R_i is the proportion of water used in rice farming. The volume of water use in rice farming was assumed constant for all reservoirs and estimated by FOs as 0.625 based on the existing water allocation practices.

A limited number of inputs are used in Sri Lankan CBF activities compared with other Asian countries (De Silva, 2003). This is because CBF activities are conducted in existing water bodies and do not utilize supplementary feeding. Labor is used as a standard input in CBF production and is sourced from collective agreements among the FO members. This is at variance with some other countries where the labour is supplied by families or is hired. Labor used for CBF production was estimated as the number of man-days actively involved in CBF related activities in one fish culture cycle. All activities of CBF production were undertaken as a group. Stocking of fish fingerlings, protecting the fish harvest from theft and harvesting were identified as the three major labor intensive factors of CBF production.

The number of fish fingerlings seeded represents the stock in the reservoirs, assuming the rate of natural mortality is relatively constant across reservoirs. The main species stocked includes several Indian carp species (catla (*Catla catla)*, rohu (*Labeo rohita)* and mrigal (*Cirrbinus mrigala*)) and Chinese carp species (bighead carp (*Aristichthys nobilis Richardson*), common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), and grass carp (*Ctenopharyngodon idella*) (Wijenayake, et al., 2005). The village irrigation reservoirs dry up to a large extent during some months of the year and hence generally do not support indigenous fish communities (Amarasinghe, 2008). Fingerling stocking choices are made by the FOs depending on the availability of fingerlings.

The different species have different growth characteristics, which may manifest itself as differences in technical efficiency. The type of fish fingerlings stocked were categorized based on their growth rates and incorporated into the inefficiency model as two dummy variables (one each for only fast and only slow growing only species, with the base being both).

The majority of reservoirs had small groups of farmers for CBF activities, consistent with best-practice (De Silva et al., 2006), although single-person aquaculture activities were found in a few reservoirs. Therefore, the stability of the group can have a considerable impact on TE, given a more stable group has a greater collective experience dealing with both management of the VISs and resolving disputes between members and other users. The government provides extension services for agriculture, and farmers were found to consult the extension officers of NAQDA and the Department of Agrarian Development (DAD) regularly when organizing agricultural activities. On average, farmers spent 17.5 hours meeting with government officials. A priori, it was expected that the time spent in consulting officials would have a positive effect on TE in CBF production as farmers would gain information helping to improve their productivity.

Agricultural activities in Sri Lanka are highly subsidized. For instance, since 2005, the government has subsidized fertilizer for rice farming. Given the supply of fingerlings is also subsidized in CBF production the impact of subsidies on TE for CBF production was also investigated.

Feeding is not undertaken but instead CBFs rely on run-off containing organic materials into the reservoirs. Animal husbandry practices in the catchment areas have a positive impact on nutrient loading of the reservoirs (De Silva et al., 2007), and previous research has shown that the number of animals (cattle and water buffalos) living in the reservoir catchment has a positive relationship with CBF production (Jayasinghe and Amarasinghe, 2007, Rabbani et al., 2004). Since the introduced fish species into the reservoirs are mainly herbivorous (De Silva et al., 2006), it can be expected that productivity would be related to the number of animals in the catchment area.

Finally, the number of months of water use for other purposes was included in the model. This was because there is a positive relationship between multiple uses of water and water productivity in VISs (Phengphaengsy and Okudaraia, 2008).

RESULTS

A three step procedure was employed to estimate the production frontier while imposing monotonicity (Henningsen and Henning, 2009). The first step involved the estimation of an unrestricted stochastic frontier using maximum likelihood estimation (MLE). The model was tested against an alternative specification (i.e. Cobb Douglas production function) and the translog was found to be more appropriate ($\chi^2_{6DF} = 15.87$). The model was also tested for the existence of technical inefficiency (i.e. a production frontier rather than just a production function) and the frontier was also found to be the more appropriate specification (χ^2_{9DF} = 33.89). Given that the functional form of the model was determined as appropriate, monotonicity was imposed during the second step and the final inefficiency model was derived in the third step.

The initial MLE estimate did not satisfy the monotonicity condition for all observations, while the quasi-concavity was satisfied for only 2.2% of the total observations. The adjusted model fully satisfied the monotonicity conditions, but was not fully convex (Table 3). The implications is that, for the 7% of observations which fall in areas that are not quasi-concave, the individual inefficiency score may be either over- or under-estimated (Sauer et al., 2006). Provided that the farmer characteristics were randomly distributed over these (and all other observations), the impact on the inefficiency model is likely to be minor, and is expected to be captured as random error in the inefficiency model.

<Tables 3 and 4 about here>

The coefficients of the estimated production frontier at each stage of the estimation process of the three steps procedure are shown in Table 3. The minimum distance estimates were generally not significantly different to the initial MLE estimates. The final estimates were derived from the scaling coefficient estimated in the final step (Table 4). As expected (Henningsen and Henning, 2009), the intercept term in the final step was not significant from zero, while the scaling coefficient was not significantly different to 1 indicating no substantial bias had been introduced into the model through the three step process.

Since the data were log-normalized, the coefficients on the level terms for each input represent its production elasticity at the mean. The production elasticity relating to water was estimated to be 0.45, meaning that an additional 10% allocation of water would increase CBF production by 4.5% percent. The elasticity corresponding to total fingerlings was around 0.27, suggesting substantial diminishing returns to stocking, and in turn reflecting limited supplies of naturally occurring feed in the reservoirs. The elasticity for labor was negative in the original model and not significantly different to zero. In the final model, the elasticity was positive but small. This suggests that groups may oversupply labor with little benefits in terms of increased production. Individuals have an incentive to supply labor to ensure they receive part of the output from the reservoir.

The inefficiency model explains a substantial proportion of the total variation in the data not already explained by the inputs (i.e. $\gamma = 0.81$) (Table 4). The estimated results of the inefficiency model are shown in Table 5. As it is an “inefficiency” models, positive coefficients indicate that the corresponding variable has a negative effect on efficiency, while coefficients with negative signs have positive effects on efficiency. Surprisingly, stocking only fish species with slow growth rates had no effect on technical inefficiency while stocking only fast growing species had a negative influence on technical efficiency. The number of cattle and water buffalos in the catchment increased efficiency, although this was only significant at the 10% level. An *a priori* assumption was that the number of cattle upstream from the reservoir would affect output through the supply of nutrients into the system. The supply of subsidized fingerlings for CBFs and the time spent meeting officials (i.e. fisheries extension officers), are shown as the most significant factors (at 1% level) influencing technical inefficiency. Group stability positively relates to TE, but is not statistically significant.

<Tables 5 about here>

The frequency distribution of TE is shown in Figure 1. The mean TE of CBF production in the sample VISs was 0.33, while the median was 0.31. This is considerably lower than that found in other studies of efficiency conducted in Asia, which ranged from 0.42 to 0.83 with a mean TE of 57% (Sharma and Leung, 2000b, Dey et al., 2000, Sharma, 1999, Iinuma et al., 1999). Given the dominance of low TE scores, VISs based CBF production in Sri Lanka could potentially be increased substantially using the existing technology if inefficiency can be reduced.

<Figure 1 about here>

DISCUSSION AND CONCLUSIONS

The main objective for the construction of village irrigation reservoirs in Sri Lanka was to harvest rainwater in the low rainfall regions to undertake rice farming. However, promoting multiple uses of water in village reservoirs for various agricultural activities created the potential to increase water productivity (Phengphaengsy and Okudaraia, 2008). Consequently since the 1980s, there has been a growing trend of releasing fish into these reservoirs. This involves stocking of hatchery–reared fingerlings, especially those carp species capable of feeding and growing on the natural productivity of the reservoirs (Ryther, 1981). In this way CBF activity adds a new dimension to increasing water productivity in VISs. While other studies have observed considerable variability in CBF productivity between VISs, and attributed this to differences in management (Pushpalatha and Chandrasoma, 2010, Wijenayake et al., 2005), this study is the first to quantitatively determine the level and drivers of technical efficiency of CBFs in Sri Lanka.

The average TE of CBFs was found to be substantially lower than average efficiency of other aquaculture practices elsewhere in Asia (e.g. see Iliyasu et al., 2014, Sharma and Leung, 2003). However, a direct comparison with these other studies is not feasible as each study estimates technical efficiency against the best practice in their own country (i.e. it is a relative measure of practices within each industry and within each country). Therefore, in absolute terms it is not valid to conclude that one country is more efficient than another. However, the lower mean in Sri Lanka does suggest that there is considerably greater variation in efficiency in Sri Lanka relative to the other Asian countries, and that a larger proportion of farmers are producing relatively inefficiently.

There are also substantially larger differences in the production system in Sri Lanka compared with the other Asian producers. In Sri Lanka, existing water bodies are used for CBFs instead of ponds. Supplementary feeding using fish feed, oil cakes or rice bran, as undertaken elsewhere (Singh et al., 2009), is not used in Sri Lanka nor is fertilization of water to enhance growth of natural food – e.g. the addition of cow dung - (Singh et al., 2009). Similarly, CBF practices in Sri Lankan village reservoirs do not involve water quality enhancement using lime (Rabbani et al., 2004, Kareem et al., 2009), urea (Rabbani et al., 2004) or chemical fertilizers (Singh et al., 2009, Sharma, 1999). Such measures are not needed in Sri Lanka given reservoir water is supplemented with nutrients derived from livestock grazing within the reservoir catchments. This contributes a large amount of nitrogen and phosphorus through their fecal matter (Jayasinghe and Amarasinghe, 2007). Similar means of supply of nutrient inputs are reported elsewhere in the literature (Nash and Halliwell, 1999, Bravo et al., 2003, Jennings et al., 2003). From the point of view of biodiversity and environmental protection, CBFs in VISs are considered as an eco-friendly development strategy (De Silva, 2003).

The volume of water available for CBFs is a highly influential factor in CBF production (see Table 3). However, there is little or no possibility of increasing the capacity of the VIS. The only practical way of increasing the residual volume in a VIS is through a reduction in the use of water in rice farming - the main user of reservoir water.

The (final) output elasticity with respect to labor is generally positive but it was not a significant input in the case of Sri Lankan CBFs. Only a limited amount of labor is required for the three phases of CBF. That is, it is used only for stocking the fingerlings, protecting the fish from poachers and harvesting. Since labor is not used for feeding, care or adding fertilizer, an increase in labor input would not result in higher production. There remains incentives, however, for excess supply of labor to persist; individual participation ensures continued membership to the group and a share of rewards from the output of the group.

The output elasticity of total fish fingerlings was 0.27 in the model. This indicates that a 10% increase in total fish fingerlings can only increase CBF production approximately by 2.7%. This suggests that most reservoirs are at (or close to) their carrying capacity.

Amongst the other factors considered, only four positively affected technical efficiency. They were group stability, number of cattle and water buffalos grazing in the catchment area, stock of slow growing fish species and the number of months that water is used by other users. The group stability measure represents the farmers' willingness to continue CBF activities for the next fish culture cycle with the same group members. This measure is an indicator of the confidence in the group to produce and to agree on collective decisions. Most importantly, collective agreements in protecting fish from fish poachers until the final harvest significantly influences efficiency. Collective decisions of such communities are dependent on homogeneity of group characteristics (Kularatne, 2009). However, group stability can also be influenced by various social and economic factors (age of farmers, education, income and employment).

A significant positive factor (at the 10% level) affecting technical efficiency is the number of animals (cattle and water buffalos) living in the catchment areas. Adding cow dung results in enhanced biological productivity and thereby increased aquaculture production (Dey et al., 2000). Studies elsewhere have also noted a positive correlation between cattle/buffalos density and the fish yield (Jayasinghe and Amarasinghe, 2007). Therefore, the number of cattle and buffalos grazing in the watershed area was included in the inefficiency model as a proxy for the amount of animal manure entering the reservoirs. As expected, the estimated coefficient relating to the number of cattle and water buffalos was significant and influenced efficiency.

Water in VISs is used for multiple uses (Renwick, 2001). Reservoirs that are located close to the village may be used for more alternative uses than those reservoirs located farther from the village. Therefore, the marginal value of water should be higher in the reservoirs that are located close to the village. The survey found that 59% of the reservoirs had fish poaching problems due to open access. Other studies have found that the costs of enforcement and monitoring represent 79% the total transaction cost of FO-organized CBF production (Senaratne and Karunanayake, 2006). It is presumed that an increase in the number of months that others use water in the reservoir may increase enforcement and monitoring costs and technical inefficiency. This situation is ultimately the result of the absence of well defined property rights which are linked with the spatial patterns of economic activities (Otsuki, 2002).

A key influential negative factor on technical efficiency is the subsidization of the supply of fingerlings for CBF activities. VISs which used subsidized fingerlings were less productive than those that did not receive the subsidy. Fingerling supply is subsidized by various sources such as non-government organizations, regional and local level government authorities, as well as direct government subsidy programs. Since fingerlings are a main cost item in CBF production, most of these subsidies are provided to farmers as a support to reduce the costs of CBF production. However, use of these subsidized fingerlings came at the cost of lower productivity.

In Anuradhapura, 66% of CBF farmers have considered the problem of open access (poaching and other problem from the villagers) as a constraint to CBF development (Senaratne and Karunanayake, 2006). The FOs are given the power to organize all agriculture-related activities by a government act. When all villagers are members of FOs in a given village, the rights of villagers to use reservoir water and the other resources are almost similar to their rights that have evolved historically. Therefore, providing subsidies to CBFs with ill-defined property rights leads to technical inefficiency. Amarasinghe and Nguyen (2009), however, have argued that subsidized fingerlings are important for the sustainability of CBF production in Sri Lanka. It is argued here that benefits of such subsidisation are received only by a small group of farmers who have agreements with FOs. Therefore, it can be argued that if subsidies are to have a positive effect on TE, then it is essential to establish adequate CBF property for village reservoirs.

The time spent on consulting government fisheries officials (i.e. fisheries extension officer of NAQDA) for extension services also has a negative influence on efficiency in CBF production. The cost of time searching for information is part of managerial transaction costs (Furubotn and Richter, 2005), and these costs may represent as much as 9% of the total transactions cost of CBF production that has been organized by FOs, and 5% for small group of VIS farmers in the Anuradhapura district (Senaratne and Karunanayake, 2006). It must be mentioned here that it is likely that the service provided by the fisheries officers is too spread out and sparse due to factors such as costs and due to other factors such as lack of appropriate technical know-how. It is also a fact that most FOs may have stronger relations with extension officers from agriculture rather than from fisheries who could provide specialized support.

Overall the results indicate there is substantial technical inefficiency in CBF production in Sri Lanka. In order to achieve efficiency gains, it is important to strengthen group stability, improve accessibility to agricultural extension support, promote a mechanism for maintaining independent investments in CBFs without depending on subsidies, and finally, ensure that water user rights are well defined. One option to address some of these issues is to introduce transferable community quotas (Wingard, 2000) in CBF production that will lead to a system of transferable water user rights. In addition, there is the opportunity to encourage livestock farming in the watershed areas within a framework of integrated agriculture (Prein, 2002) which is designed to create sustainable organic CBFs. Integration of a crop-animal system and implementing a community transferable quota system (CTQ) are not a new phenomenon in rice farming in Sri Lanka (Ulluwishewa, 1995). As such, a revival and re-establishment of such historical systems as formal institutions under the umbrella of a FO system will be useful in increasing TE in CBF production.

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Table 1. *Description of variables of the inefficiency model*

Variables	Description
Group stability	Continuation of CBFs activities with the same group in the following year (Dummy variable)
Time spent on meeting officials	Visiting time of government officials to provide extension services (hours)
No rain water risk for CBFs	Yearly adequate rain water availability for CBFs (Dummy variable)
Subsidised fingerlings supply	Fingerling or money received from third party to invest CBFs (Dummy variable)
No of cattle and buffalos	Number of cattle and water buffalos grazing or living in the reservoir catchment
Slow growing fingerlings	Mrigal (*Cirrhinus mrigala Hamilton*), rohu *(Labeo rohita Hamilton*), Nile tilapia (*Oreochromis niloticus L.*) and the other species considered as slow growing species
Fast growing fingerlings	Common carp (*Cyprinus carpio L.*), bighead carp (*Hypophthalmichthys nobilis*) and catla (*Catla catla Hamilton*)
Number of months of water use for other uses	Number of months whereby water is used for other uses

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Table 2. Summary statistics of variables involved in the SFM for CBF production

Variables	Mean	Std. Dev	Minimum	Maximum
Output (kg)	2715.48	3739.899	18	20000
Individual volume of water[a]	2.04	1.89	0.07	9.62
Labor (man days)	30	38	2	164
Total fish fingerlings (number)	131654	11807	1000	91500
Ln water	0.25	1	-2.60	2.26
Ln water *Ln water	1.15	1.3	0.000	6.78
Time spent to meet officials	17.53	19.8	0	96
Number of cattle and buffalos	185	233	0	1300
Number of months water used for other	5.28	3.63	0	12
Group stability	-	0.5	0	1
Rain water risk for CBFs	-	0.5	0	1
Subsidised culture cycle	-	0.5	0	1
Slow growing fish fingerlings	-	0.5	0	1
Fast growing fish fingerlings	-	0.3	0	1

Notes. a) Actual volume unknown; the surface area (in Ha) of the reservoir is used as a proxy.

Table 3. Coefficients of the production frontier

	First Step			Second Step			Third step
Variables	MLE Coeff.	Std. Error		Min. distance Coeff	Diff.	Diff/ Std. Error	Final Coeff
Constant	1.25	0.24	***	1.49	-0.24	-1.00	1.50
Ln(water)	0.45	0.07	***	0.45	0.00	0.06	0.45
Ln(labor)	-0.06	0.09		0.00	-0.06	-0.74	0.00
Ln(fingerlings)	0.29	0.10	***	0.27	0.02	0.20	0.27
Ln^2(water)	0.40	0.13	***	0.16	0.23	1.85	0.16
Ln(water)xLn(labor)	0.04	0.07		0.00	0.04	0.57	0.00
Ln(water)xLn(fingerlings)	-0.20	0.10	**	-0.09	-0.11	-1.07	-0.09
Ln^2(labor)	0.08	0.14		0.00	0.08	0.58	0.00
Ln(labor)xLn(fingerlings)	0.01	0.10		0.00	0.00	0.05	0.00
Ln^2(fingerlings)	0.12	0.17		0.07	0.05	0.29	0.07
Model performance							
Monotonicity							
• Water	84.3						100
• Labor	25.8						100
• Fingerlings	94.2						100
Quasiconcavity	2.2						92.9
σ^2	2.69	0.52	***				
γ	0.79	0.07	***				

* significant at 10% level; ** significant at 5% level; *** significant at 1% level

Table 4. Final stochastic frontier model (stage 3)

Variables	Estimates	Std. Error	
Intercept	0.014	0.271	
lcFitted	0.999	0.121	***
σ^2	2.717	0.482	***
γ	0.815	0.064	***

*** significant at 1% level

Table 5. Inefficiency model

Variables	Initial estimates			Final estimates		
	Coeff	Std. Error		Coeff	Std.Error	
Group stability	-0.3684	0.3321		-0.3862	0.3249	
Time spend meeting officials	0.0171	0.0069	**	0.0166	0.0066	**
Rain water risk for CBFs	0.3530	0.3145		0.3188	0.2947	
Supply of subsidized fingerlings	0.7982	0.3295	**	0.8909	0.3140	***
No of cattle and buffalos	-0.0011	0.0008		-0.0012	0.0007	*
Slow growing fingerlings	-0.1561	0.3333		-0.1651	0.3021	
Fast growing fingerlings	0.4044	0.4739		0.5506	0.4406	
Number of months of other water use	-0.0366	0.0426		-0.0408	0.0409	

* significant at 10% level; ** significant at 5% level; *** significant at 1% level

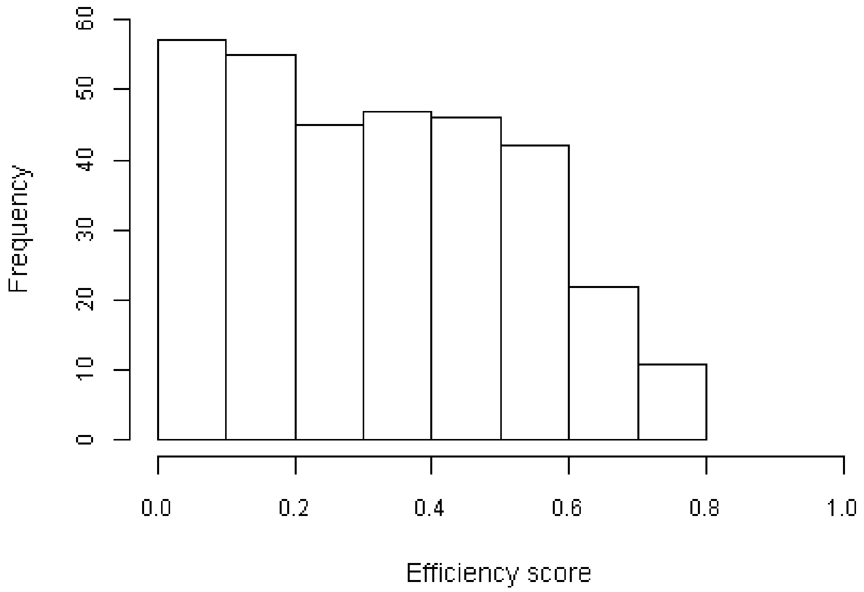

Fig.1. Frequency distribution of TE estimates