Conventional vs Natural Flood Control and Drainage Managements in a Tidal Coastal Zone: An Evaluation from a Productive Efficiency Perspective

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This paper was presented at the 89th Annual Conference of the Agricultural Economics Society, University of Warwick, England, 13 - 15 April 2015.

Abstract: Two competing flood control and drainage management (FCDM) systems, namely, the 'silt-dredging and regulative-drainage management (SRM)' and the 'tidal river-basin management (TRM)' systems were implemented in the Southwest coastal zone of Bangladesh as a safeguard for agricultural production. The fundamental difference between these two FCDM systems is that the SRM is a conventional system based on hard engineering structure and heavily dependent on routine dredging; in contrast, the TRM is a natural system. This paper primarily evaluates these two contrasting and competing FCDM systems from the perspectives of productive efficiency, going beyond the traditional approach which often takes an engineering perspective. Evaluation of these two FCDM systems has been made on three distinctive measurements including 'technical efficiency', 'yield-gap' and 'potential yield increment'. The results reveal that the conventional flood defence system (SRM) marginally outperforms the natural system (TRM) in terms of productivity with paddy. This is despite SRM being more expensive to deliver, as well as the fact that, due to a relative sea-level rise with the SRM system, it is likely to become increasingly expensive in the future. In contrast, TRM benefits from counteracting a relative sea-level rise in an environmentally friendly way, keeping maintenance costs low.

Keywords: Flood control and drainage management; productive efficiency; potential yield increment, stochastic frontier analysis; yield-gap.

JEL Codes:C10, C12, C13, D24, Q00, Q54

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Acknowledgements: The author is indebted to Dr. Neil A. Powe and Dr. Ken G. Willis, respectively Senior Lecturer in Planning and Emeritus Professor of Economics of the Environment at the School of Architecture, Planning and Landscape, Newcastle University, for their constructive comments and suggestions.

1. Introduction

Understanding a flood control and drainage management (FCDM) system is important because it has the potential to influence socioeconomic and environmental issues. In agriculture it often emerges as a crucial player in determining the productivity, which is a big concern in agriculture (Gedara et al., 2012; Kalirajan and Shand 2001;Lio and Hu 2009; Rahman et al., 2009). It is well known that any major intervention (e.g., irrigation project, flood control and drainage management etc.) in the water resources sector affects agriculture of the area where it has been implemented. Hence, changes in the agriculture of the area occur through modification of the existing production environment whereby resource usage patterns, employment opportunities, cost of production, total output etc. take new shapes and sizes. In reality, each sort of management/intervention exerts a distinctive type of impact on topography and soil quality that leads to modification of the existing production environment, which in turn brings about some changes in the production system. It is, therefore, very likely that a new input-output relationship for a crop would evolve compared to the pre-intervention situation or different managements/interventions would appear with different input-output relationship for the same crop. Thus, a comparative study of the managements/interventions from the perspective of agricultural productivity is very important. A good number of empirical studies including Eknayake and Jayasuria, 1987; Kalirajan and Shand, 1986; Seyoum et al., 1998; Wadud and White, 2000, have performed comparative evaluation of different types of interventions in the water resources sector, in terms of agricultural productivity. Indeed, any major intervention in the water resources sector has significant economic and policy implications. However, it is imperative to understand/evaluate alternative or competing management options from the perspective of agricultural productivity as far as it relates to agricultural land. The area in consideration is also important here because a considerable part of the total changes relate to the topography of the area.

Two competing and contrasting flood control and drainage management (FCDM) systems were implemented in the coastal zone of Bangladesh as a safeguard of agricultural production (ADB 2007;SMEC 2002). One of these systems is called 'the silt-dredging and regulative-drainage management' (SRM), which is a typical conventional flood control system, heavily dependent on routine dredging while another is termed as 'the tidal river-basin management' (TRM), which is a natural system, evolved from the wisdom an long experience of the coastal people of Bangladesh, and importantly, it addresses flooding and drainage problems in an environmental friendly way. Apart from the contrasting features, these two systems are competing as well in the sense that there was a long debate over their selection—the policy makers as well as engineers preferred the SRM system while the stakeholders and a quarter of water resources experts favoured the TRM system (CEGIS 1998; Alam and Hasan 2009; Islam and Kibria 2006). Hence an evaluation of these two FCDM systems is very important for further understanding. Since these FCDM systems were implemented as a safeguard to agriculture, evaluation of these systems should involve their contribution to agriculture.

Comparative evaluation of flood control and drainage management systems often involves assessment of flood protection potential and/or reckoning of flood frequency/risk, overlooking their productivity potential. An evaluation which does not consider the productivity potential of FCDM therefore provides only a partial assessment when it (the FCDM system) is in the agricultural sector (Bos and Boers 1994). Indeed, there is a gap in the literature due to the fact that FCDM systems are evaluated based only on their capability to protect the area from flooding thereby neglecting the productive efficiency of the production environments they bring forth. This article however, attempts to provide further understanding of these two FCDM systems and then addresses this gap in the literature by evaluating them from the perspective efficiency in agriculture.

2. Contrasting Features of the SRM and TRM Systems

The basic principles and operational mechanisms of the two FCDM systems are quite different. The SRM is a hard engineering structure (regulators, embankments etc.) based system which resembles to the polder[1] system. Routine sediment management is a must which is vital to keep

1. A polder is a low-lying tract of land enclosed by embankments/dykes that form an artificial hydrological entity, meaning it has no connection to outside water other than through outlet devices. This sort of flood management often creates drainage congestion; since the tides are not allowed to go beyond the river channels, the river beds become elevated with sediment deposition from the tides. Thus, the hydrology under polders eventually leads to gravity drainage problems and then waterlogging hazards.

the SRM system operational; indeed, it is the glaring aspect that distinguishes SRM from the so-called polder system. Sediment deposited downstream of the regulator(s) is removed regularly by dredgers. Thus, SRM system involves huge costs for its overall operation and maintenance. Meanwhile, the most important advantage of the SRM system is that it controls salinity effectively as tides are not allowed to enter into the floodplain (*beel*) area. In contrast, under the TRM system, tidal flows are allowed to enter into the floodplain areas in a planned way so that sediments borne by tides are deposited on the bed of the floodplain which elevates the land level of the floodplain. At the same time, sediment-free outgoing tidal flows scour out the silts/sediments (if any) on the way (i.e., river beds) back to the sea, thereby rehabilitate gravitational drainage problems and keep the drainage channels functional. Over time, the features of TRM have been improved; TRM is now a blend of traditional practices and modern technology (CEGIS, 1998; SMEC, 2002).

3. Theoretical Framework and Analytical Methods

An intervention can be assessed by the productive efficiency of a production unit operating within the environment created by the intervention itself. The logic here is that the input-output relationship in the production unit is mostly determined by the production environment, while the production environment is brought forth by the intervention. Thus, performance of the production unit is eventually attributive to the intervention itself. This principle is widely practiced in comparative performance evaluation of different types of intervention in many sectors, including agriculture, power generation (Diewart and Nakamura 1999; Hiebert 2002; Iglesias et al., 2010), education (Hesmati and Kumbhakar 1997; Johnes 2006; Johnes and Yu 2008), finance and banking(Ferrier and Lovell 1990) and so on. Similarly, productive efficiencies in producing a product in two different environments caused by two different interventions can be ascribed to the interventions accordingly and, thus, their relative performances can be compared. Indeed, this is an established practice, by which a wide variety of interventions, management systems, policy measures, programmes and so on are assessed, often in terms of productive efficiency of the product(s) concerned (see Coelli et al., 2005, p. 1; Battese and Coelli 1996, Kalirajan 1981,1982, 1984; Kumbhakar et al., 1989; Von Baily et al., 1989).

Neo-classical theory of production forms the theoretical basis of productive efficiency. Productive efficiency is basically an output-input ratio and it differs from one production unit to another for a number of reasons. Different production units experience different production relationships (or output-input ratios) due to varying states of technology or random disturbances (associated with different production environments); in some cases, existing technology is exploited more efficiently in a particular environment (Shapiro and Muller, 1977, cited in Herdt and Mandac, 1981, p. 376). In reality, combinations of all or some of these factors lead to different production units eventually appearing with different productive efficiency ratings. Originally, Farrell (1957) coined the term 'productive efficiency' and highlighted the importance of this concept in production economics. Productive efficiency has three types of interpretation: technical, allocative and economic, or cost. However, vast majority of empirical studies employed estimates of technical efficiency in relative performance evaluation. Kalirajan and Shand (1999) contend that the idea of technical efficiency is central to measuring the performance of production units; whilst Reifschneider and Stevenson (1991) report that frontier functions provide the basis for defining efficient performance.

Literature on comparative performance evaluation provides several alternative approaches, namely, data involvement analysis (Wadud and white 2000, Coelli, Rahman and Thritle 2003, distance function approach (Rahman et al., 2011; Atkinson and Primont 1998) and so on, to determine the relative position of different interventions in terms of productive efficiency. Of these, the frontier production function method proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977) occupies a broader space in the literature because of its sound and robust theoretical basis (Solis et al., 2009; Singh et al., 2009; Conradie et al., 2006; Karagiannis and Sarris, 2005; Karagiannis et al., 2002; Wilson et al., 2001, 1998; Sharma and Leung, 1999, 2000; Iinuma et al., 1999; Seyoum et al., 1998; Battese and Broca, 1997; Audibert, 1997; Battese et al., 1996).

3.1 The Stochastic Frontier Model

The generic form of the stochastic production frontier model can be represented as

$$y_i = f(\boldsymbol{x_i}\,;\boldsymbol{\beta}).\exp(\xi_i - \tau_i)\; \xi_i - \tau_i = \varepsilon_i \text{and } -\infty \ \leq \xi_i \leq \infty; \tau_i \geq 0 \qquad (1)$$

where y_i denotes the output of the i-th farm, *(i=1, 2, 3, . . . n)*

$x_i = (x_{1i}, x_{2i}, \ldots x_{mi}) \geq 0$, a $(1\times m)$ vector of known inputs used in producing output of the i-th farm;

β is a $(m\times 1)$ vector of unknown parameters to be estimated;

ξ_i, represents symmetric random errors, and is assumed to be independently and identically distributed as $N \sim (0, \sigma_\xi^2)$;

τ_i, represents asymmetric non-negative random errors, and is assumed to be independently and identically distributed such that τ_i is obtained by truncation at zero from below the normal distribution with mean μ and variance σ_τ^2 (i.e., $iid\ N(\mu, \sigma_\tau^2)$. Furthermore, ξ_i and τ_i are assumed to be independent of each other and of the input vector $\boldsymbol{x_i}$.

The inefficiency component τ_is is assumed to be a function of a set of explanatory variables for the inefficiency effects specified in the stochastic frontier model as

$$\tau_i = z_i\delta + \omega_i = \mu_i + \omega_i \qquad (2)$$

where ω is a random variable assumed to be truncated from a normal distribution with a mean of 0 and variance σ^2_ω ; the point of truncation is $-z_i\delta$, and it maintains the condition $\omega_i \geq -z_i\delta$ in order to ensure the non-negative value of τ_i. More specifically, τ_i can be defined as a non-negative truncation of the distribution with a mean of $-z_i\delta$ and variance σ_τ^2i.e., $N \sim (-z_i\delta, \sigma_\tau^2)$;

where

$z_i = (z_{1i}, z_{2i}, \ldots z_{ki}) \geq 0$, a $(1\times k)$ expresses the vector of farm- and management-specific inefficiency variables related to the technical inefficiency of the i-th farm; and δ is a $(k\times 1)$ vector of unknown coefficients.

However, this article applies SFA as the principal analytical tool in evaluating the two competing and contrasting flood management systems with reference to paddy production. Hence the production system complies with Zellner et. al., (1966) assumption that output is endogenous and farms maximise the mathematical expectation of profit which suggests that estimation of technical efficiency (TE) is an appropriate approach to evaluate the management systems (Battese and Coelli 1995; Kumbhakar et al., 1991; Kumbhakar1987). In addition to technical efficiency this study considers measurement of some useful yardsticks namely, yield-gap and potential yield increment (PYI) in evaluating the FCDM systems. Given the challenges of cross sectional data, it is expected that if the three way assessments (TE, yield-gap and PYI) produce similar results with respect to evaluation of the two competing FCDM systems, it would confirm the robustness of the analytical approaches.

4. Data and Descriptive Statistics

The data on paddy production used for this article were collected from a probabilistic sample survey conducted in 2011/2012 crop year in two floodplain areas—beel Dakatia and beel Bhaina—located within the KJDRP command area where the two FCD management systems, SRM and TRM, are operational for more than a decade. In selecting the farm households from the study areas, multistage sampling procedures were used, maintaining the principle of proportionality for a representative number of samples from each area. Initially, each beel area was divided into upland and lowland parts, according to the elevation of the beel bed, and then stratified random sampling techniques were applied to select villages from each (upland and lowland) part of the two beels. A total of 14 villages were chosen from 41 villages situated within or around the two beels, and a total of 357 samples, comprised of small, medium and large farm households, were selected from these 14 villages, applying stratified and simple random sample techniques. The stratification of households was done based on land holdings following the criteria used by Bangladesh Bureau of Statistics (BBS 1997).Stratification helps reduce sampling error (Warwick and Lininger, 1975, p. 75) and thereby provides accuracy in the estimates (Cochran 1977, p. 89).This study persuaded a face-to-face interview technique to collect primary data using structured questionnaires. However, from beel Dakatia, a total of 205 households were taken into consideration, of which 123 (or 60%) were from lowland areas and 82 or (40%) from upland areas; the sample sizes from upland and lowland areas for beel Bhaina were 99 (or 65%) and 53 (or 35%) respectively, comprising a total of 152 samples.

4.1Variables in the stochastic production frontier (SPF) model

Before selecting the variables for the stochastic production frontier (SPF) model, extensive consultations with the farmers and stakeholders were made keeping in mind the empirical studies in this field of research. Seed, land preparation, irrigation, labour, pesticides and chemical fertilizers are common factors of paddy production in Bangladesh and (perhaps) elsewhere in the world. Generally, researchers choose most of the variables from the abovementioned factors when analyzing the frontier production function of paddy (see Sharif and Darr (1996), Kalirajan and Shand (1986); Dawson et al., (1991); Battese and Coelli (1995); Wadud and White (2000); Rahman et al., (2009); Rahman et al., (2012a) and Rahman et al., (2012b). However, besides these common variables this study has taken into consideration additional variables, namely dewatering, dummy for dewatering, and dummies for soil qualities, in order to cover the environmental issues involved. Bivariate correlation is usually used in detecting the presence of collinearity among the variables (Lavaine, 2015; Liu, 2010; Rouf and Jahan, 2001), and it was found that there is no collinearity problem among the variables of this analysis. Table 1 presents a summary of statistics for the variables of the SPF model for paddy production using the SRM system in beel Dakatia and the TRM system in beel Bhaina. Specifications for most of the input variables in this study match with other, similar studies, including Wilson et al., (2001) and Rahman et al., (2012b).

5. Empirical Stochastic Frontier and Inefficiency Models

The present study develops stochastic frontier models to predict the technical efficiency of farms for two different management systems, drawing on Battese and Coelli (1998 and 1995), Coelli and Battese (1996) and Kumbhakar (1994) models. However, there are a considerable number of zero observations in the data set as it is not unusual in the developing country agriculture. Zero values are often replaced by ‘one’ or an arbitrary value that lies between zero and one. This practice is open to criticism in that it is not independent of measurement and it is very likely that this procedure will result in biased estimates of the parameters if the number of zero observations constitutes a significant proportion of total observations (Battese, 1997). This study, however, adopts a procedure that provides unbiased estimates following the suggestions prescribed by Battese (1997). In fact, this procedure has already gained wider acceptance (see Battese, Malik and Broca, 1993 and Battese and Coelli, 1995)because it provides reliable estimates of parameters.

Table 1

Summary of statistics of the variables in the stochastic production frontier model

Variables	Option	Mean	Max	Min	Std. dev	t-ratio
Seed cost (tk)	SRM	732.35	1286.72	272.72	230.13	-9.83***
	TRM	991.25	1783.02	330.58	266.39	(0.000)
Dewatering (litre)	SRM	33.39	76	5.26	16.6	18.34***
	TRM	10.31	24	0	6.03	(0.000)
Land Prepa-ration (tk)	SRM	1382.36	2931.03	0	713.17	5.202***
	TRM	1088.34	1818.18	294.12	329.3	(0.000)
Urea (kg)	SRM	71.49	111.11	3.03	22.87	-14.89***
	TRM	117.86	177.97	41.67	32.96	(0.000)
TSP (kg)	SRM	58	100	18.38	20.06	1.77
	TRM	53.48	98.04	0	26.44	(0.08)
MP (kg)	SRM	31.06	73.33	0	16.37	4.64***
	TRM	22.99	62.5	0	16.09	(0.000)
Irrigation (litre)	SRM	9.85	66.67	0	10.14	-20.60***
	TRM	38.68	68.18	3.53	14.88	(0.000)
Labour (man-days)	SRM	32.99	57.14	19	7.19	-8.319***
	TRM	40.71	68.88	20.83	9.62	(0.000)
Peaty:D1	SRM	0.341	1	0	0.475	-
Clay:D2		0.171	1	0	0.377	
Sandy-loamy:D1	TRM	0.224	1	0	0.418	-
Clay- loamy:D2		0.214	1	0	0.414	
Farm-specific variables						
Age	SRM	39.83	70	18	11.03	1.64
	TRM	37.91	70	19	10.82	(0.10)
Years of schooling	SRM	8.25	17	0	3.65	-1.14
	TRM	8.65	15	0	2.97	(0.257)
Experience	SRM	11.65	30	3	4.94	-4.48***
	TRM	15.3	45	2	9.09	(0.000)
Ownership Dummy	SRM	0.639	1	0	0.482	-
	TRM	0.32	1	0	0.466	-
Yield (kg)	SRM	2670.44	4148.15	1500	612.26	0.20
	TRM	2657.78	3769.84	1621.62	552.07	(0.840)

*Note: *** means significant at 1% level (p<.01); ** means significant at 5% level (p<.05)*
** means significant at 10% level (p<.10);* (Figures in parentheses indicate p-values)

Source: Field survey

5.1 Empirical stochastic production frontier and technical inefficiency models for paddy production with the SRM System in beel Dakatia

$$\begin{aligned} ln\, y_i = \beta_0 + \beta_1\, ln\, x_{1i} + \beta_2\, ln\, x_{2i} + \beta_3\, ln\ [\max\ (x_{3i}, 1 - D_{1i})] + \beta_4\, D_{1i}\ (x_{4i}) + \beta_5\, ln\, x_{5i} \\ + \beta_6\, ln\, x_{6i} + \beta_7\, ln\, x_{7i} + \beta_8\, ln\ [\max\ (x_{8i}, 1 - D_{2i})] + \beta_9 D_{2i}\ (x_{9i}) \\ + \beta_{10}\, ln\, x_{10i} + \beta_{11} D_{3i}(x_{11i}) + \beta_{12} D_{4i}\ (x_{12i}) + \xi_i - \tau_i \end{aligned} \tag{3}$$

5.2 Empirical stochastic production frontier and technical inefficiency models for paddy production with the TRM System in beel Bhaina

$$\begin{aligned} ln\, y_j = \beta_0 + \beta_1\, ln\, x_{1j} + \beta_2\, ln\ [\max\ (x_{2j}, 1 - D_{1j})] + \beta_3\, D_{1j}\ (x_{3j}) + \beta_4\, ln\, x_{4j} + \beta_5\, ln\, x_{5j} \\ + \beta_6\, ln\, x_{6j} + \beta_7\, ln\ [\max\ (x_{7j}, 1 - D_{2j})] + \beta_8 D_{2j}\ (x_{8j}) + \beta_9\, ln\, x_{9j} \\ + \beta_{10}\, ln\, x_{10j} + \beta_{11} D_{3j}\big(x_{11j}\big) + \beta_{12} D_{4j}\ (x_{12j}) + \xi_j - \tau_j \end{aligned} \tag{4}$$

The notations *x,* and *D* refer to the input variables and dummy variables respectively while the subscripts *i* represents the model with SRM and *j* TRM systems; however *i-th* item ≠ *j-th* item.

For the SRM model-

D_1 assumes value 'One' if cost for land preparation is positive, and 'Zero', otherwise;

D_2 assumes value 'One' if cost for irrigation is positive, and 'Zero', otherwise;

D_3 assumes value 'One' if soil type is peaty, and 'Zero', otherwise; and

D_4 assumes value 'One' if soil type is clay, and 'Zero', otherwise.

For the TRM model-

D_1 assumes value 'One' if cost for dewatering is positive, and 'Zero', otherwise;

D_2 assumes value 'One' if MP was applied to grow paddy, and 'Zero', otherwise;

D_3 assumes value 'One' if soil type is sandy loamy, and 'Zero', otherwise; and

D_4 assumes value 'One' if soil type is clay loamy, and 'Zero', otherwise.

5.3 Model for technical inefficiency effects for both models

$$\tau_i = \delta_0 + \delta_1 z_{1i} + \delta_2 z_{2i} + \delta_3 z_{3i} + \delta_4 D_{5i}\ (z_{4i}) + \omega_i \tag{5}$$

The notations *z,* and *D* refer to the inefficiency variables and dummy variable respectively for both models with SRM and TRM systems. D_5 assumes value 'One' if primary decision maker is the owner of the entire paddy land and 'Zero', otherwise.

5.4 Estimation techniques

The basis of the most commonly used output-oriented measure of technical efficiency (TE) is the ratio of observed output to the corresponding frontier output (maximum feasible output). Thus, the technical efficiency of the *i-th* farm is

$$TE_i = \frac{\text{observed output}}{\text{stochastic frontier output}} = \frac{y_i}{\exp\ (x_i' \beta + \xi_i)}$$

$$= \frac{exp\ (x_i' \beta + \xi_i - \tau_i)}{exp\ (x_i' \beta + \xi_i)} = exp\ (-\tau_i) \tag{6}$$

This ratio measures the output of the i-th farm compared to the fully-efficient farm that can produce the maximum feasible output using the same input vector in an environment characterised by $\{exp\ (\xi_i)\}$. By definition, the value of the measure of technical efficiency must lie between zero and one. Since the value of TE_i may vary across the farms and even for the same farm overtime; it is a random variable, not a parameter. The estimation technique primarily involves probability density functions and joint density functions of the error components (ξ and τ) and the composed error component term (ε), where, $\varepsilon = \xi - \tau$. Following Kumbhakar and Lovell(2000) derivations:

The joint density of τ and the composed error term ε, is

$$f(\tau, \varepsilon) = \frac{1}{(2\pi\sigma_\xi \sigma_\tau)\ \Phi(\mu/\sigma_\tau)} . exp \left(-\frac{(\tau-\mu)^2}{2{\sigma_v}^2} - \frac{(\varepsilon+\tau)^2}{2{\sigma_\tau}^2} \right) \tag{7}$$

The marginal density of ε is given by

$$f(\varepsilon) = \sigma^{-1}.\varphi\left(\frac{\varepsilon+\mu}{\sigma}\right).\Phi\left(\frac{\mu}{\sigma\lambda}-\frac{\varepsilon\lambda}{\sigma}\right).\left[\Phi\left(-\frac{\mu}{\sigma_\tau}\right)\right]^{-1} \quad -\infty \leq \varepsilon \leq +\infty \qquad (8)$$

where $\sigma = (\sigma_\xi^2 + \sigma_\tau^2)^{1/2}$ and $\lambda = \sigma_\tau/\sigma_\xi$. Φ (.) refers to the standard normal cumulative density function, and φ (.) indicates standard normal density function.

After algebraic manipulation the mean of the inefficiency component is obtained by

$$E(\tau_i|\varepsilon_i) = \hat{\tau} = \mu_{*i} + \sigma_*\left[\frac{\varphi(-\mu_{*i}/\sigma_*)}{1-\Phi(-\mu_{*i}/\sigma_*)}\right] \qquad (9)$$

The technical efficiency of *i-th* farm, according to Battese and Coelli's (1988) formulation, is

$$TE_i = E\,\{\exp(-\hat{\tau_i})\,|\varepsilon_i\}$$

$$= \left[\frac{1-\Phi\left(-\frac{\mu_{*i}}{\sigma_{*i}}+\sigma_{*i}\right)}{1-\Phi\left(-\frac{\mu_{*i}}{\sigma_{*i}}\right)}\right].\exp\left(-\mu_{*i}+\frac{\sigma_{*i}^2}{2}\right) \qquad (10)$$

where, $\mu_{*i} = (-\sigma^2_\tau\,\varepsilon + \mu\sigma^2_\xi)/\sigma^2$; $\sigma^2_{*i} = \sigma^2_\tau\,\sigma^2_\xi\,/\sigma^2$; Φ (.) refers to a standard normal cumulative density function, and φ (.) indicates a standard normal density function.

Of the two most commonly used functional forms for stochastic frontier analysis e.g., Cobb-Douglas (C-D) and Transcendental logarithmic (translog) forms, this study justifies the Cobb-Douglas functional form for this analysis. As a matter of fact that the translog functional form gives many low t-ratios and extreme values for certain estimate of this study. There are studies including Tadesse and Krishnamoorthy (1997) and Dawson et al., (1991) that experienced similar problems with estimates of the translog model, which led them to switch over to the Cobb-Douglas model. The maximum likelihood estimation of the parameters (including *β's* and variance parameters $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_u^2/\sigma^2$), using the Cobb-Douglas frontier model, are presented in tables 2 and 3 for the SRM and TRM systems respectively.

Table 2

Maximum-likelihood estimates of the stochastic frontier model for paddy production with SRM in beel Dakatia

Variables	Notations	Parameters	Coefficients	Std. errors	t-ratios
Constant		β_0	1.839	0.399	4.60***
Seed	x_1	β_1	0.146	0.043	3.40***
Dewatering	x_2	β_2	-0.110	0.029	-3.84***
Land prep	x_3	β_3	0.009	0.026	0.35
LP Dummy	D_1	β_4	-0.070	0.197	-0.36
Urea	x_5	β_5	-0.044	0.034	-1.13
TSP	x_6	β_6	0.209	0.042	4.95***
MP	x_7	β_7	0.006	0.019	0.32
Irrigation	x_8	β_8	0.007	0.018	0.41
Irrig Dummy	D_2	β_9	-0.013	0.052	0.24
Labour	x_{10}	β_{10}	0.139	0.082	1.69*
Soil Dummy	D_3	β_{11}	-0.126	0.032	-3.95***
Soil Dummy	D_4	β_{12}	-0.069	0.039	-1.75*
Inefficiency Model					
Constant		δ_0	0.161	0.212	0.76
Age	z_1	δ_1	0.006	0.003	1.85*
Schooling	z_2	δ_2	0.002	0.007	0.25
Experience	z_3	δ_3	-0.017	0.009	-1.79*
Owner Dummy	D_5	δ_4	-0.041	0.051	-0.80
Model Diagnostics					
Sigma-squared		σ^2	0.053	0.016	3.34***
Gamma		γ	0.786	0.161	4.87***
Log-likelihood			50.68		

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

(Figures in parentheses are OLS estimates)

Source: Own estimation

Table 3

Maximum-likelihood estimates of the stochastic frontier model for paddy production with TRM in beel Bhaina

Variables	Notations	Parameters	Coefficients	Std. errors	t-ratios
Constant		β_0	1.1133	0.5532	2.0480**
Seed	x_1	β_1	0.0061	0.0540	0.1139
Dewatering	x_2	β_2	0.0843	0.0240	3.5173***
Dewat Dummy	D_1	β_3	-0.1512	0.0742	-2.0374**
Land prep	x_4	β_4	0.0238	0.0584	0.4075
Urea	x_5	β_5	0.2150	0.0450	4.7771***
TSP	x_6	β_6	-0.0447	0.0168	-2.6639***
MP	x_7	β_7	0.0026	0.0180	0.1460
MP Dummy	D_2	β_8	0.0187	0.0398	0.4695
Irrigation	x_9	β_9	0.1180	0.0367	3.2154***
Labour	x_{10}	β_{10}	0.2415	0.0558	4.3239***
Soil Dummy	D_3	β_{11}	-0.1562	0.0468	-3.3405***
Soil Dummy	D_4	β_{12}	0.0468	0.0333	1.4050
Inefficiency model					
Constant		δ_0	0.3719	0.2403	1.5478
Age	z_1	δ_1	-0.0067	0.0050	-1.3491
Schooling	z_2	δ_2	0.0003	0.0101	0.0330
Experience	z_3	δ_3	0.0055	0.0059	0.98752
Owner Dummy	D_5	δ_4	0.1159	0.0692	1.6741*
Model Diagnostics					
Sigma-squared		σ^2	0.0338	0.0121	2.8047***
Gamma		γ	0.9648	0.2644	3.6491***
Log-Likelihood			71.9153		

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

(Figures in parentheses are OLS estimates)
Source: Own Estimation

6. Results and Discussions

6.1 Estimated parameters and overall fitness of the models

Results show that most of the inputs variables and all of the diagnostic variables are statistically significant, which indicate that the econometric models are a good fit overall. Both the estimates of σ^2 (sigma-squared) and γ (gamma) are statistically significant at 1% level for both models testifying the adequacy of the stochastic frontier model. The signs of the coefficients of all the input variables for both options are as expected; however, the signs of two estimates relating to two chemical fertilizers, one in each management option, require additional explanation. Urea appears with negative estimate in beel Dakatia but positive estimate in beel Bhaina; whilst, the reverse is true for TSP, i.e., beel Dakatia and beel Bhaina record respectively positive and negative estimates for TSP. Plausible explanations for these types of estimates are the soil contents and/or salinity condition of the respective beels. For example, in beel Bhaina soil salinity could be the reason for the negative estimate of TSP. Salinity hampers the growth of the plants, while TSP is usually applied to enhance the growth of the plants. It may be deduced that farmers in beel Bhaina use more TSP to fight against salinity.

Dewatering, a rare but important environmental factor, is highly significant ($p<0.01$) in both beels, but with different signs, as expected. Turning to another environmental factor soil quality, the coefficients of dummies for peaty soil and clay soil with the SRM system are -0.126 and -0.069 respectively. Meanwhile, with the TRM system, the coefficient of dummy for sandy-loamy soil is -0.156, and that for clay-loamy is 0.047.Labour is a vital factor in the agriculture of a developing country like Bangladesh, since the country's agriculture sector is still far away from considerable scale of mechanization. The maximum likelihood estimates of the labour for beel Dakatia and beel Bhaina are 0.139 ($p < 0.10$) and 0.242 ($P <0.01$), which are very close to those of Wadud and White (2000), Sharif and Dar (1996), Dawson et al., (1991) and Kalirajan and Shand (1986). Finally, the elasticity of returns to scale (RTS) for the SRM and TRM options are respectively 0.362 and 0.647, meaning both systems are operating under decreasing returns to scale. However, it (RTS) indicates that the TRM option is a more promising management system than its counterpart as far as paddy production is concerned.

6.2 Estimates of variables in the inefficiency model

In the case of inefficiency model, the variables 'experience' and 'ownership dummy' in the SRM system have negative coefficients, implying that these variables contribute towards reducing inefficiency in paddy production. The rest of the inefficiency variables except *age* have positive coefficients in both management systems. In beel Dakatia, the coefficient of *age* is positive, meaning younger farmers are more efficient than the old. This finding is similar to the results obtained by Battese and Coelli (1995), Ajibefun et al., (1996), Seyoum et al., (1998) and Wadud and White (2000). On the other hand, the coefficients of *years of schooling* are with positive signs for both the beels, which conforms with the observations of Kalirajan (1984), Wadud and White (2000), Coelli and Battese (1996). Perhaps easy communication between the farmers, particularly by dint of mobile phone, has significantly reduced the difference in terms of use of resources between farmers with higher and lower levels of education.

6.3 Discussion of technical efficiency scores and statistical test

The predicted technical efficiency scores for beel Dakatia range from 0.4833 to 0.9593, with a standard deviation of 0.1057, while those for beel Bhaina vary from 0.4784 to 0.9801, having a standard deviation of 0.1167. The mean scores for beel Dakatia and beel Bhaina are 0.7808 and 0.7685 respectively, which is slightly favourable for SRM system. These mean scores are very close to those of Kumbhakar (1994) and Sharif and Dar (1996). Independent sample t-test (table 4) shows that the mean technical efficiency scores for SRM and TRM farmers are not statistically different from each other. In addition, Levene's F-test of homogeneity of variances is consistent with the independent sample t-test. The above findings indicate that the two management systems are similar in terms of productive efficiency in paddy cultivation.

Table 4

Independent sample t-test for technical efficiency by management option

Options	Mean tech efficiency	Maximum	Minimum	Levene's test for equality of variance	t-test for equality of means
SRM	0.782 (0.106)	0.9593	0.4833	1.911	1.124
TRM	0.769 (0.117)	0.9801	0.4784	-0.168	-0.262

* Figures in the parentheses are standard deviations
Source: Own estimation

6.4 Efficiency scores by frequency distribution and percentage share

By grouping the efficiency scores into decile range the number of farms in each group and their percentage share were calculated in order to compare the competing management options thoroughly.

Table 5

Technical efficiency (TE) scores with 10% class intervals by frequency distribution and percentage share

Range of TE	Frequency		Percentage share	
	SRM	TRM	SRM	TRM
Below 0.50	2	1	0.98	0.66
0.50 - >0.60	7	13	3.41	8.55
0.60 - >0.70	35	30	17.07	19.73
0.70 - >0.80	60	45	29.27	29.61
0.80 - >0.90	73	39	35.61	25.66
0.90 and over	28	24	13.66	15.79
Total	205	152	100.00	100.00

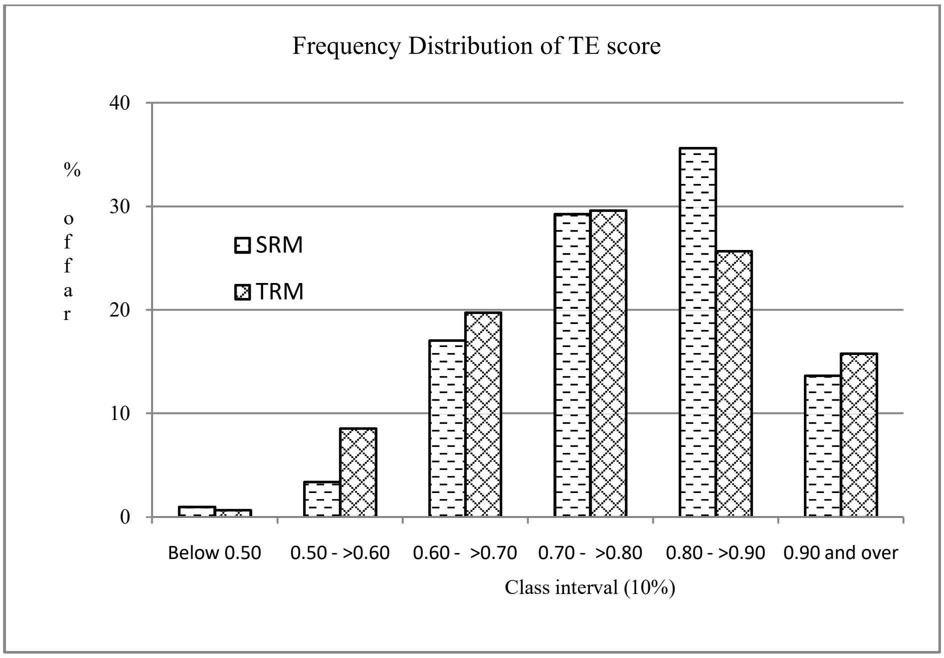

Figure 1: Histogram for percentage of farms based on technical efficiency score by management option

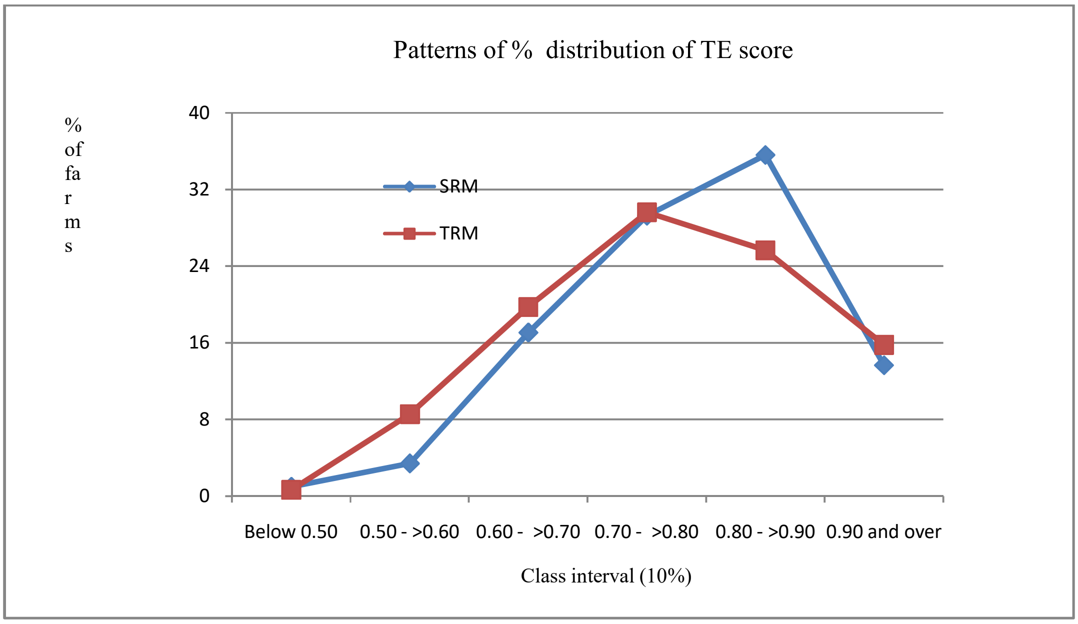

Figure 2: Patterns of scores for technical efficiency by management option

It is evident from table 5 and figures1 and 2 that a higher percentage of farms using the SRM option attain upper range efficiency scores. For example, 49.27% percent of farms from the SRM group achieved an efficiency score of 0.80 and above, whereas only 41.45% of farms from the TRM option fall into this category. A contrasting picture is seen for the efficiency range of below 0.60, where the percentage of TRM farms is higher (9.21%) than its counterpart (4.39%). However, the middle range percentage of TRM farms marginally exceeds its counterpart by 3%. That means in the SRM option, farms performed relatively better.

7. Evaluating SRM and TRM with Productivity Related Yardsticks

This study employs two yardsticks, yield-gap and potential yield increment (PYI) to evaluate the competing and contrasting FCDM system apart from productive efficiency estimates. If the findings of these assessments match with that of the productive efficiency measures, it would testify the appropriateness of applying the productive efficiency approach. However, measurement of yield-gaps with different production environments indicates their relative performance/contribution to agricultural productivity. A considerable number of empirical works employed yield-gap to this end, however, with diverse types of objectives such as examination of organic agriculture and conventional agriculture (de Ponti et al., 2012; Seufert, 2012; Stanhill, 1990; Lotter, 2003; Goulding et al., 2009); inquiring into the nutrient and water stress conditions (Boling et al., 2011); and investigating rain-fed and irrigated farming (Yang et al., 2004; Aggarwal et al., 2008). PYI is a variant of yield-gap; nevertheless, it provides further understanding about the production environment in consideration (Bravo-Ureta and Rieger 1991).

7.1 Yield-gap and related issues

Generally, yield-gaps refer to the mathematical difference between yield potential and average farmers' yield in a specified spatial and/or temporal state (Lobell et al., 2009; van Ittesum et al., 2013). While yield potential is defined as the yield level which is grown with a sufficient supply of nutrients and water, and all the stresses including pests, diseases and weeds are effectively controlled in an adapted environment (Evans 1993, p. 292). Cassman (1999, p. 5954) criticised this definition, terming it 'straightforward'. Indeed, yield potential is not a quantity but a concept, which makes its estimation both complicated and challenging (Cassman 1999, p. 5954).

However, Herdt and Mandac (1981) introduced two well-known types of yield-gap which are often used in empirical studies. The first one is calculated as the difference between the maximum yields at the experimental station and the maximum yield under farmers' conditions, whilst the second one is the difference between the maximum possible yield under farmers' conditions and the farmers' observed yield. This study however, applies the second type to this analysis.

7.2 From technical inefficiency to yield-gap

By definition, the technical efficiency of a farm (say, the i-th farm) is the ratio of its actual output to the output that could be produced using the same input bundle by a farm which is fully efficient (Coelli et al., 2005, p. 244); hence, the measure of technical efficiency assumes a value between zero and one. Thus, any farm with a technical efficiency of less than one is inefficient by definition. The extent to which the technical efficiency score falls short of one can be termed the '(technical) efficiency gap' (See Dawson et al., 1991; Hadley, 2006). Due to inefficiency or the efficiency gap, a farm's output level remains below the frontier level (or the maximum feasible level of output). Accordingly, the measure by which observed output falls short of the maximum feasible output level is termed the yield-gap.

The formula for measuring the yield-gap, (Y_g), per unit of land can be given by

$$Y_{gi} = \left[\left(\frac{Y_{ai}}{1-E_{gi}}\right) - Y_{ai}\right] / L_i \qquad (11)$$

Where Y_{gi} = yield-gap of the i-th farm

Y_{ai} = actual (observed) output of the i-th farm

E_{gi}= efficiency gap for the i-th farm

L_i = land area of the i-th farm in standard units (acres)

The term $\left(\frac{Y_{ai}}{1-E_{gi}}\right)$ represents the maximum feasible output or frontier output of the i-th farm and is denoted by *(Y_{fi})*.

So, the formula for the yield-gap (Y_g) of the i-th farm can be simplified as

$$Y_{gi} = \left[Y_{fi} - Y_{ai}\right] / L_i \qquad (12)$$

Table 6
Yield-gap (kg) for paddy production due to inefficiency with SRM and TRM options

Options	Average	Difference	Max	Min	Std. deviation	F-test	t-test
SRM	719.181	88.14	1672.21	161.43	330.32	15.78***	-2.06**
TRM	807.324		2149.28	75.37	443.84	(0.000)	(0.040)

*** Significant at 1% level; ** significant at 5% level
(Figures in parentheses indicate the p-values)

Source: Own calculation

It is evident from the Table 6 that both the statistical tests i.e., Levene's test of homogeneity of variance and t-test have been rejected at 1% and 5% levels of significance respectively. Overall, the picture of yield-gap statistics shows that the SRM option is in a more favourable position compared to the TRM option, and the gap is moderately wider.

7.3. Potential Yield Increment

Potential yield increment (PYI)refers to the additional output that could be produced if the farm was technically efficient and it is calculated against hundred weight. The concept of 'yield-gap' provides a general notion about the performance of production units in alternative production environments. However, interpretation of this measurement in terms of 'potential yield increment' can provide further understanding about the productive efficiency of the production units (Bravo-Ureta and Rieger, 1991).

Potential yield increment (Y^{pi}) for the i-th farm can be calculated by

$$Y_i^{pi} = \left[\frac{\left\{ \left(\frac{Y_{gi}}{1-E_{gi}} \right) - Y_{ai} \right\}}{L_i Y_{ai}} \right] \Big/ 100^{\,-1} \qquad (13)$$

(Here Y_i^{pi} refers to potential yield increment for the i-the farm; other notations are as mentioned above)

Table 7
Potential yield increment (hundredweight) in paddy production with SRM and TRM options

Management Options	Observed output (average)	Technically efficient output (average)	Potential yield increment	Std. dev	F-test	t-test
SRM	2670.44	3414.885	30.532	19.837	2.277	-1.259
TRM	2657.78	3456.151	33.371	21.948	(0.132)	(0.209)

Note: Figures in the parentheses indicate the p-values
Source: Own calculation

Table 7 shows that the average potential yield increment per hundredweight for SRM is 30.53 (kg), whilst this amount for the TRM option is 33.37 (kg). That means, on the whole, SRM farms have emerged as better performers compared to their TRM counterparts regarding the potential output increment.

8. Hypotheses Testing and Decision Rules

A model for technical inefficiencies can only be estimated if the technical inefficiency effects, τ_i, are stochastic and have particular distributional properties (Coelli and Battese 1996). The following properties of the inefficiency effect are tested with log-likelihood ratio test. The first null hypothesis (H_0: $\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$) specifies that the inefficiency effects are not present in the SPF model. The second null hypothesis (H_0: $\gamma = 0$) states that the inefficiency effects are not stochastic; hence, if the parameter γ is zero, the variance of the inefficiency effects will also be zero (Battese and Coelli 1995, and Sharma and Leung, 1999). The third null hypothesis (H_0: $\delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$), indicates that technical inefficiency effects have a traditional half-normal distribution (with a mean equal to zero), as originally proposed by Aigner et al., (1977). Rejection of these null hypotheses indicates that inefficiency effects are present and stochastic, and a standard stochastic error component model is not appropriate for half-normal distribution of the technical inefficiency effects (Sharma and Leung, 1999). Finally, the fourth null hypothesis (H_0: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$) states that coefficients of all the explanatory variables in the inefficiency model are zero, which implies that the technical inefficiency model follows the same truncated normal distribution with a mean equal to δ_0, as suggested by Stevenson (1980). Rejection of this hypothesis indicates that joint effects of the inefficiency variables is significant, although the individual effect(s) of one or more of the variables may be statistically insignificant (Battese and Coelli, 1995); indeed, this test justifies the inclusion of the of the inefficiency model. Table 8 reports the results of the hypotheses tests and decision in this connection.

Table 8
Hypothesis tests and decisions

Null hypothesis	Log-likelihoods	Test statistic	Critical value (5%)	Decision
Beel Dakatia (SRM)				
H_0: $\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$	41.738	17.89	11.911	Rejected
H_0: $\gamma = 0$	47.659	6.05	5.138	Rejected
H_0: $\delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$	44.464	12.44	9.488	Rejected
H_0: $\delta_1 = \delta_2 = \delta_3 = 0$	44.716	11.936	7.815	Rejected
Beel Bhaina (TRM)				
H_0: $\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$	62.695	18.44	11.91	Rejected
H_0: $\gamma = 0$	68.283	7.264	5.138	Rejected
H_0: $\delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$	64.71	14.41	9.488	Rejected
H_0: $\delta_1 = \delta_2 = \delta_3 = 0$	62.694	18.442	7.815	Rejected

Note: The critical values regarding the variance parameter γ are taken from Table 1 of Kodde and Palm (1986).

All the null hypotheses are rejected at least 5% level of significance, meaning the stochastic frontier models used in this analysis are appropriate.

10. Summary and Conclusion

In this evaluation process, the technical efficiency scores of the farms for both management systems are the principal indicator of performance. The technical efficiency scores of the farms for the SRM system range from 0.4833 to 0.9593, with a mean score of 0.782, while this range for TRM is 0.4784 to 0.980, with a mean score of 0.769. An independent sample t-test shows that the mean scores of the two competing management systems are not statistically different from each other. The standard deviations of these scores are also very close, which was checked using Levene's test for equality of variances. These results show that both management systems are similar in terms of their productive efficiency in producing paddy. The frequency distribution and percentage share of technical efficiency scores for SRM and TRM farms show that SRM is better than TRM, to some extent, in terms of productive efficiency estimates. For example, about 41percent TRM farm have an efficiency score of 0.80 and above, whereas more than 49 percent SRM farm fall into this category. The SRM system is also at favourable side in the lower range of efficiency ratings (identified as being below 0.60), representing a lower percentage of farms in this range. Meanwhile, in the middle range of efficiency scores, the percentage of TRM farms marginally exceeds its counterpart. On the other hand, the elasticity of returns to scale (RTS) for the SRM and TRM options is respectively 0.362 and 0.647, meaning a 1% increase in all inputs would result in a 0.36% increase in paddy production in SRM, while in TRM it would be 0.65%. Hence, the TRM option is more promising than its counterpart.

Yield-gaps for the two competing management options, SRM and TRM, are respectively 719.181 (kg) and 807.324 (kg) per acre of land. These gap-measurements indicate that the SRM option outperforms its counterpart, TRM, in terms of the agricultural productivity for paddy. Like yield-gap, potential yield increment (PYI) demonstrates that the SRM option performs better than TRM in agricultural production. On average PYI measures are 30.532 and 33.371 for the SRM and TRM options respectively.

The above findings make it clear that, in most cases, the SRM option marginally outperforms TRM. However, if counteractive measures to relative sea-level rise are taken into consideration, the tidal river-basin management (TRM) system overwhelmingly outperforms the silt-dredging and regulative-drainage management (SRM) system. In order to cope with global warming, counteracting the relative sea-level rise should not be taken lightly. Furthermore, the SRM appears to be more expensive to deliver, as well as the fact that due to relative sea-level rise with the SRM system, it is likely to become increasingly expensive in the future. Therefore, if the overall evaluation is taken into consideration, the TRM system gains the upper hand.

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