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Economic analysis of development policies with reference to large-scale water control infrastructures and rural intensification in the Mekong River Delta: a case study from Vietnam

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ABSTRACT

This study conducts a Cost-benefit analysis of dyke heightening in the Vietnam floodplain to explore some of economic issues associated with three interrelated aspects of the Mekong Development Programme (MDDP) in Vietnam, namely: (i) the implications of switching to more intensified agriculture and aquaculture; (ii) the effects of a more intensive use of agro-chemicals, and (iii) the construction of large-scale water control infrastructure. The study incorporates environmental and ecological economic perspectives in its analysis. The finding of strongly negative social and private net benefits as a consequence of dyke heightening led the study to the questioning of the economic effectiveness of the MDDP. It is intended that the work will hold interest for both decision-makers and local people concerned with water control infrastructures and intensified farming practises. It could also serve to provide an important lesson for other areas of the Mekong Basin that are planning similar development schemes.

KEYWORDS

Agricultural intensification; cost-benefit analysis; dyke; large-scale water control infrastructure; rice intensification

1. Introduction

Large river deltas around the world have proved to be very important environmental resources throughout human history. These deltas support large population settlements, as well as providing improved navigation, better agricultural production techniques, and flood protection. Delta development policies, such as intensifying agriculture and large-scale watercontrol infrastructures, appear to promote these desired benefits. However, by altering the annual hydrologic regime, many development programmes generate undesirable impacts on the ecosystem and the environment. Consequently, there is a need to consider not only economic but also ecological and environmental factors to effectively manage the world's deltas. The Vietnamese Mekong Delta (VMD), situated near the Mekong River, is an instance.

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The Mekong Delta Development Programme (MDDP) has transformed the delta ecologically and economically in recent times. The objective of this programme was to lift the delta's agricultural and aquacultural productivity. This programme has resulted in large-scale flood and salinity control infrastructures, which in turn has sought to maximise land usage for highly intensive monocultures, for example, use of three continuous rice croppings per year or intensive shrimp aquaculture, in former flood-prone and saline areas. Intensive use of agro-chemicals has also played an important role in intensifying land usage. This programme continues the policies created in the 1990s and 2000s that emphasised the intensification of rice and shrimp production in order to enhance national food security and exports.

This article investigates the economic implications of the MDDP to suggest how a more sustainable future strategy could be developed, given there is pressure to meet population growth and economic development needs. This article focuses on the most recent phase of the MDDP wherein current targets for floodplain agriculture is the production of three rice crops per year using high dykes to completely prevent floods. Hence, two-rice crop systems, which were enabled by the use of low dykes to delay floods, are now being converted to three-rice crop systems with dyke heightening (Le et al. 2007). At present, both the two-rice crop systems and three-rice crop systems have become the dominant types of land use on the floodplain. There are now thousands of high dykes in the Mekong Delta (MD) (AGSDI 2013). In only 12 years, the three-rice crop areas in the four provinces located in this floodplain have increased sevenfold, from 53,500 ha in 2000 to 403,500 ha in 2012 (Duong et al. 2014).

This article presents the empirical application of a cost-benefit analysis to a dyke-heightening project in An Giang province. The term the 'low dyke system' refers to use of low dykes and its associated two rice crops and one natural fish crop, while the 'high dyke system' refers to use of high dykes and its associated three rice crops. These terms are utilised to approach the economic efficiency of the MDDP from the viewpoint of the case for a dyke heightening project. The article also incorporates environmental and ecological economic perspectives in its analysis and hence enables an appreciation of the complexity and integrated nature of the ecology and agricultural/aquacultural technologies that the MDDP is embedded in. A key implication is that dyke heightening may establish a feedback loop of perpetual reliance on costly dykes and agro-chemicals, and continuing environmental and ecological degradation. It is argued that dyke heightening does not seem to be a viable option for the MD from both social and private perspectives. The CBA results hence create substantial doubts about the case for further heightening of dykes in the MD, a process that is, however, still in progress. Since all three interrelated aspects of MDDP, namely a shift to more intensified agriculture and aquaculture; (ii) the more intensive use of agro-chemicals; and (iii) the construction of large-scale water-control structures, are described in terms of costs and benefits of a dyke heightening project, the findings imply that the overall strategy of the MDDP should be reconsidered.

2. Background

The farm dykes have been developed in the VMD over the last 40–45 years have significantly transformed agricultural production in the region. Likewise, these infrastructure developments have been closely associated with recent initiatives to shift from balanced to intensive cropping in the floodplain.

A few decades ago, the cropping system in the floodplain consisted of cultivating one floating rice crop during the flood season. Although this cropping system was environmentally benign, it provided low yields for Vietnamese farmers (Nguyen 2012). Floodplain agriculture is now more intensified. With the construction of the dykes, the previous cropping system was replaced by the two-rice-cropping system in the low dykes and three-rice-cropping system in the high dykes; these systems have become the dominant types of land use in the delta (Le et al. 2007). High dykes totally prevent floodwater from flowing into the fields and low dykes delay the effects of flooding, which have enabled the farmers in VMD to intensify their rice production. Accordingly, these intensified farming systems have transformed Vietnam from a rice importer to one of the world's largest rice exporters. The Ministry of Agricultural and Rural Development (MARD) believe that the benefits from the third rice crop outweigh any associated extra costs, including the damages caused by dyke breaching (Nghe 2011).

On the other hand, when dyke heightening alters floodplain hydraulics, they can also alter the floodplain ecosystem values. One of the key benefits of Mekong floodplains is that it provides resources for the agriculture and fishery sectors, which are both essential for local livelihoods, and thus have large economic values (Baran, Jantunen, and Chong 2007; MRC 2010). Tong (2017) raised the concern that the intensified rice production obtained from the third rice crop may come at the cost of ecological sustainability, which is necessary to maintain productivity of both rice and fishery production.

A number of empirical studies have shown evidence of the environmental problems in VMD due to dyke heightening. The studies of Hashimoto (2001), Le (2008), and Nguyen (2012) showed that the fishes that naturally move downstream to VMD during the flood season have been lost, and consequently have been replaced in value by the third crop.

Dyke heightening can also result in loss of biodiversity, particularly loss of natural fish. A study in China found that natural fish can act as a bio-control agent in rice (Xie et al. 2011). Likewise, dyke heightening can result in the loss of natural flood sediments, which possess a balanced formula of complex nutrients (Duong et al. 2011); and loss of natural mechanism to flush out toxins in the high-dyke areas (Pham 2011). All of these create unfavorable conditions for rice cultivation, and consequently negatively impacts rice productivity. Likewise, planting three rice crops continuously is against good agricultural practices. For example, it is not recommended in integrated pest management (IPM) as IPM encourages crop rotation and long fallow periods. A study conducted in 1999 in the Mekong Delta found that farmers who followed the two-rice-cropping system had slightly higher rice yields per crop and higher income per crop, as compared to those who followed the three-rice-cropping system (Berg 2002). The negative impacts of the latter system on rice productivity were further confirmed by a long-term three-rice-cropping experiment (i.e. 24 years) in the Philippines (Dobermann et al. 2000). Cumulatively, Dobermann et al. (2000) showed that yields had decreased by 38–58% within the 24-year period of growing three rice crops a year. The average yield reduction ranged from 1.4% to 1.6% for each crop per year. Intensive use of agro-chemicals in crop cultivation is a characteristic of rice intensification triggered by dyke development (NCST 2005). Rice intensification may also drive farmers to apply more pesticides and fertilizers per crop. Howie (2011) reported a 40% difference in rice yield per ton of fertilizer between rice plantations in low-dyke and high-dyke areas in sites where high dykes had been built for more than 10 years. Huynh (2011) argued that farmers with rice monoculture had more expenditure per rice crop than those farmers with rice rotation and intercropping. This may be because rice monoculture causes the soil to be less fertile. Overusing fertilizers has also led to higher pest and disease infestation, which consequently drives farmers to use more pesticides (Huan et al. 2005). The most recent study by Tong (2017) describes the two rice crop that exists with low dykes as 'balanced cropping' since it includes, as part of the rice field ecosystem, natural fish, other aquatic animals and flood sediments provided during the flood season. It is argued that planting three crops in high dykes ('intensive cropping') cannot provide a sustainable alternative to balanced cropping, either from an economic or an ecological viewpoint. This is primary because of the need to forgo balanced cropping and the traditionally important by-product outputs such as natural fish as a consequence. The better performance of balanced cropping over intensive cropping implies that the adverse environmental effects of farming conversion involve changes in ecological processes. These processes that may not be well understood but which far surpass short-term issues of profitability from a third rice crop in importance.

Thus, the issue of dyke heightening is controversial, especially when the impacts of high dykes and the intensified rice production in the floodplain are considered. The International Union for Conservation of Nature (IUCN), and other researchers, raise the question as to whether the economic benefits that such infrastructure brings to farmers are sustainable taking into account the environmental and ecological impacts of high dykes and of intensified rice production (Buu 2013; Hashimoto 2001; IUCN 2011). Even experts from the Dutch government, who assisted in building the VMD high dykes in the 1990s, now recommend restoring the floodplain to its natural state or using the two natural depression areas in the Plain of Reeds and the Long Xuyen Quadrangle to store floodwater during the flood season. They reason that these two areas are necessary to reduce the flood peak discharges in the VMD and to regulate saline water intrusion during the dry season (MNRE & MARD 2013). Noticeably that Tong (2017) suggested that the construction of large-scale water control infrastructures such as further dyke heightening should not be pursued since agricultural intensification, which is its main aim, does not make economic sense. However, this is not a comprehensive economic analysis of dyke heightening in the VMD. It hence does not provide a comprehensive and reliable set of estimates for the costs and benefits of dyke heightening and not yet examine how, and to what extent, various stakeholders are advantaged or disadvantaged by such process.

3. Methodology

This section presents the costs and benefits included in the CBA analysis. It also reviews the use of profit function, the PEA tool for assessing the impacts of dyke heightening on rice profit and on pesticide-use externalities for estimating the mentioned costs. This section also discusses the data collection methods used in this study and the criteria for choosing the study sites that enabled the author to get the information needed for the CBA.

3.1. Cost-benefit analysis

Dyke heightening creates various benefits and costs in An Giang province. This study focused on the direct benefit of dyke heightening, namely, the effects of dyke heightening on the overall social and private profit of growing a third rice crop. Four costs were estimated in this study as follows: (1) the decline in profits from the first and second crops in the high-dyke areas; (2) the increase in pesticide-use external costs; (3) the foregone net revenues from the natural floodplain fishery due to the loss of floodplain in the high-dyke areas; and (4) the infrastructure cost of dyke heightening. The infrastructure cost includes construction, maintenance, and management costs.

The 'low-dyke system' was used as a base scenario so that we could compute the differential between low-dyke and high-dyke values. Since the benefits and costs occur at different times or can change over time, CBA estimates the net present value (NPV) from dyke heightening as follows:

$$NPV = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+r)^t} \qquad \text{Equation (1)}$$

where: NPV – net present value of the project in T year (time horizon); B_t – benefits of heightening in year t; C_t – costs of heightening in year t; r – discount rate.

The specific valuation techniques to measure the first two costs, namely the decline in profits from the first and second crops in the high-dyke areas and the increase in pesticide-use external costs, are discussed in the next section.

3.2. Valuation techniques

3.2.1. Profit function to estimate the decline in profits from the first and second crops

This article employs a restricted profit function to identify the determinants of the rice profit in An Giang province. The assumption is that all farmers used to achieve the same average profits for the first two crops before some of them happened to be in high dykes areas and hence decided to add the third crop. Accordingly, it provides the lost net income from the first two crops which is specifically attributable to the MDDP. This number will be utilised later in CBA as the benefit that the rice farmers have to forgo for the first two crops when they switch from the annual two rice crops to the three rice crops on the floodplain.

The economic concept of a profit function is applied to clarify if the MDDP and other factors affect farmer profitability. As defined in Varian (1992), the profit function is one way of summarising a firm's technology. In short, the profit function can be used to show how maximised profits accruing to individual farmers depend on input prices, the fixed factors of production that cannot be altered in the short run, and on choice of cropping system.

In the study, a dummy independent variable reflecting the MDDP was included in the profit function to determine if the MDDP has an effect on the rice profit of rice farmers and its magnitude. We pooled the average profit of the first two crops of the two systems in this analysis. We excluded the third crop in this function as this crop is only available in the intensive cropping and thus causes lack of comparability across the two systems. The role of the third crop under intensive cropping is analysed separately. Finally, the estimated absolute monetary impact of the MDDP effects on rice profit could then be identified.

Accordingly, profit is estimated by the following basic profit function:

$$\pi^* = \pi(W^*, C, Z, E, D) \qquad \text{Eq. (2)}$$

where:
π^* = normalized profit, defined as gross revenue minus variable cost divided by the farm-specific output price;
W^*= vector of variable input prices divided by output price;
C = vector of fixed input factors of the farm;
Z = vector of social-economic characteristics of farmers;
E = vector of farming conditions;
D = MDDP dummy variableassigned value 1 for intensive cropping is used and value 0 if balanced cropping is used.

The profit function is supposed to take the translog functional form:

$$\ln \pi^* = \alpha_0 + \sum_{j=1}^{5}\alpha_j \ln W_j * + \frac{1}{2}\sum_{j=1}^{5}\sum_{k=1}^{5}\tau_{jk} \ln W_j * \ln W_k * + \sum_{j=1}^{5}\sum_{l=1}^{2}\varphi_{jl} \ln W_j * \ln C_l + \sum_{l=1}^{2}\beta_l \ln C_l + \frac{1}{2}\sum_{l=1}^{2}\sum_{t=1}^{2}\phi_{lt} \ln C_l \ln C_t + \sum_{m=1}^{4}\omega_m Z_m + \sum_{n=1}^{3}\eta_n E_n + dD \qquad \text{Eq. (3)}$$

where:
π^*= restricted profit (total revenue minus total cost of variable inputs) normalized by price of output (P)
W_j*, W_k* = price of the j^{th} input (W_j) normalized by the output price (P), $j = k$;
W_1* = normalized price of fertilizer; W_2*= normalized wage of labour; W_3* = normalized price of the machine power; W_4* = normalized price of seed; W_5*= normalized price of pesticide;
C_l, C_t = quantity of fixed input, $l = t$;
C_1 = the land cultivated (ha); $C_{2=}$ the number of working age labour;
Z_m= social – economic characteristics of farmers;
Z_1 = age (years); Z_2= gender (1 = male, 0 = female); Z_3= the number of school year (years); Z_4= attendance in training sessions (1 = Yes, 0 = No);
E_n= farming conditions

E_1 = variable of serious disease incidence happening during the studied year (1 = Yes, 0 = No); E_2= variable for soil quality (1 = fertile soil, 0 = other soils); E_3 = variable off-farm income ratio (%); and

D = MDDP factor (intensive cropping =1, balanced cropping =0).

The fixed factors include the land cultivated, the number of working-age individuals in the family and the farm capital used (Rahman 2003). In our case, machinery is not considered as 'farm capital used' or a fixed factor as in other studies. This is due to the fact that machines are mainly rented so it is possible to change this input in the short term. In addition, converting to three rice crops implies changing agricultural practices (such as time for land preparation) and hence may require changing the hours needed for renting machinery.

3.2.2. Cost-transfer method (pesticide environmental accounting) to estimate the increase in external costs

As mentioned, intensive use of agro-chemicals is one consequence of pursuing the MDDP or dyke heightening. Three rice crops within high dykes involves the application of higher amounts active pesticide ingredients per cop than two rice crops existing in low dykes. In addition, since dyke heightening permits one additional third crop, this increases further the pesticide externalities imposed on the environment annually compared to balanced cropping (Tong 2017). Note that increases in fertiliser use also cause externalities such as the 'blue baby' syndrome in infants (Tegtmeier and Duffy 2004). However, this study only estimates the externalities associated with pesticide use and not the overall external cost of using agro-chemicals. Also the consequences of pesticide use for farm profitability are not taken into account because pesticide expenses are already included as part of rice production costs.

The increase in pesticide's external costs are the costs arising from dyke heightening due to the increase in pesticide-use externalities. It equates to the differences in those costs between intensive and balanced farming of An Giang. We use the PEA tool to estimate the external costs per crop for each farming system.

Due to the lack of data on pesticide-use external costs in Vietnam, we applied the PEA method to estimate the increase in pesticide-use external costs. The PEA is the only method capable of comparing the external costs of pesticide use across different farming systems (Praneetvatakul et al. 2013). In this study, the PEA tool is a cost transfer method that transfers other international external cost studies to Vietnam. It combines the EIQ method and a methodology for absolute estimates of external pesticide costs that has been used in the UK, the USA and in Germany (Leach and Mumford 2008). Specifically, the model converts mean external costs of the average pesticide in those three countries to Vietnam. It then assigns the EIQ values to convert mean external costs of the average pesticide to external cost of each individual pesticide. This tool, therefore, provides comparative external cost of pesticide use for each farming system. More details are as follows:

PEA use mean external costs of the average pesticide obtained from the studies in the UK, the USA and the Germany:

As the PEA relies on the absolute estimates of external costs across the three countries as mentioned, the external costs that we refer to in this article are the costs included in those studies. Here Pretty et al. (2000) categorised pesticide external costs into 6 categories: pesticides in sources of drinking water, pollution incidents, fish deaths and monitoring costs, biodiversity/wildlife losses, landscape/tourism value, bee colony losses and acute effects of pesticides to human health. The external costs of pesticides include two types of damage costs: (1) the treatment or prevention costs – those costs incurred to clean up the environment and restore human health to comply with legislation or to return these to an undamaged state; (2) the administration and monitoring costs – those costs incurred by public authorities and agencies for monitoring environmental, food and health parameters.

PEA use the EIQ values obtained from list of pesticides 2012 provided by the Cornel University:

The EIQ method requires users to assign scores (namely EIQ units) based on a range of toxicological and environmental fate variables for a specific pesticide. This is a holistic approach used to rate the human and eco-toxicological behaviour of specific pesticides: See Kovach et al. (1992). Specifically, the EIQ methodology comes with a database for the eco-toxicological effects of active ingredients in eight categories, including the effects on applicators and pickers (farm workers), the effects on pesticide residues on groundwater leaching and food consumption (consumers), and the effects on aquatic life, bee, birds and beneficial insects (the environment). The EIQ base values of each individual pesticide from the list of pesticides in 2012 provided by Cornel University are data input in PEA for estimating external costs (see New York State Integrated Pest Management (2012) for the list of those pesticides and further detail of EIQ tool).

Specifically, based on the PEA model, we calculate the so-called total external cost (TEC) for a farming system as follows:

$$TEC = \sum_{p=1}^{m} \left[A_p * p_{active} * \sum_{c=1}^{8} \left[EC_c * F_c * x\left(F_{agemp} | c = 1, 2\right) \right] * F_{gdppc} \right] \quad \text{(Eq. 4)}$$

where:

A_p: application rate (kg/hectare) of a pesticide p for a total of m pesticides.

p_active: proportion of active ingredients.

EC_c: external cost base values of 1 kg of active ingredient for the average pesticide in EIQ categories.

F_c: toxicity level of pesticide (0.5 = relatively low level of toxicity, 1.0 = medium toxicity, and 1.5 = highly toxic).

c: category c of the eight categories that were evaluated in developing the EIQ model.

F_{agemp}: ratio of Mekong Delta's share of employment in agriculture to the average share of agricultural employment in Germany, the UK, and US (weighted by GDP).

F_{gdpc}: ratio of Vietnam's per capita GDP to average per capita GDP in Germany, the UK, and US (weighted by GDP).

Illustration of the steps used to calculate the external cost of pesticide use for a farming system is in Appendix A.

3.3. Survey materials and methods

3.3.1. Criteria in choosing study sites

We used primary data as inputs for the CBA. Survey data were used to calculate the profit from the third rice crop, while the decrease in profit from the first and second rice crops were estimated using the profit function. The survey data on pesticide use were also the data used in the cost-transfer method via the PEA method. To get those data, interviews were conducted intensive and balanced cropping farmers from Thoai Son and Chau Thanh districts in An Giang province. An Giang province is located in the northwest of Mekong Delta. This province is a rice-intensive province where major dyke-heightening developments have been implemented over the past 10 years. An Giang also has the highest rates of increase and the highest areas of intensive cropping (Duong et al. 2014). More than half of the rice planted areas in An Giang province now use intensive cropping associated with 1939 high dykes (AGSDI 2013; AGGSO 2013).

Both selected sites experienced the same flooding levels before high dykes were built (Figure 2, Table 1). These two sites are located in close proximity to each other, with only a canal separating them. Hence these sites formerly shared similar social

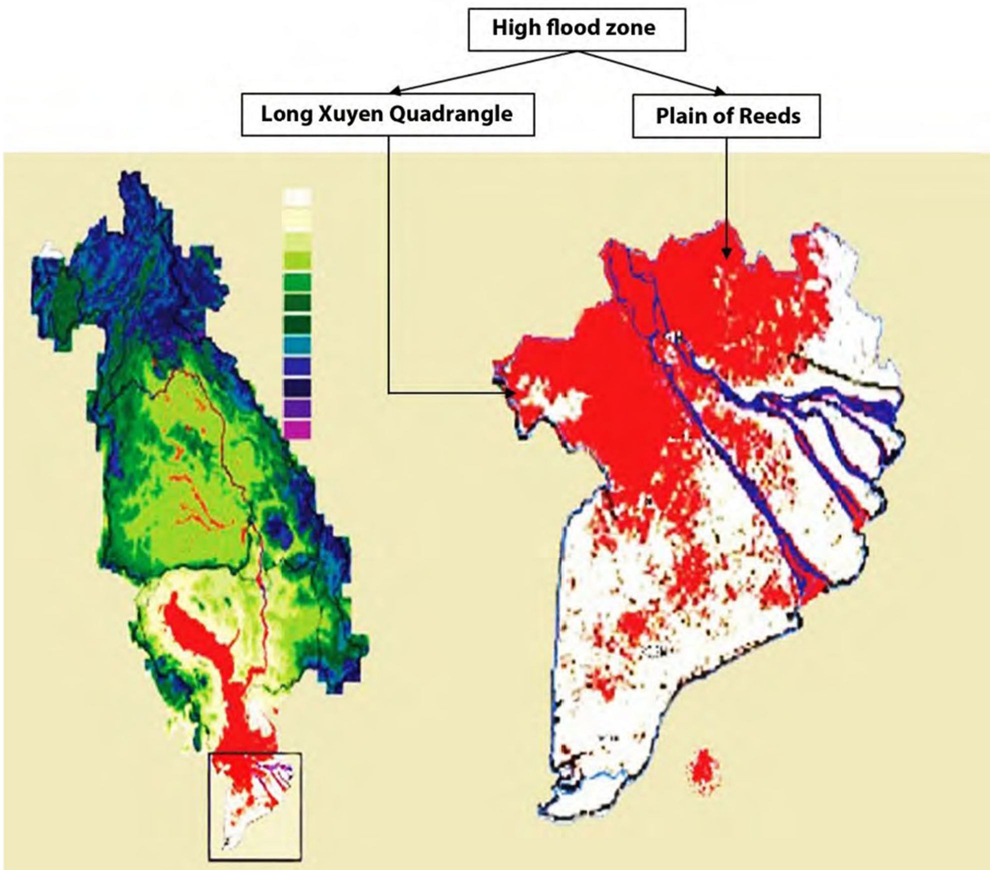

Figure 1. Flooded area (in red), beginning of September 2000, Mekong Basin and Mekong Delta (*Source*: Le et al. 2007).

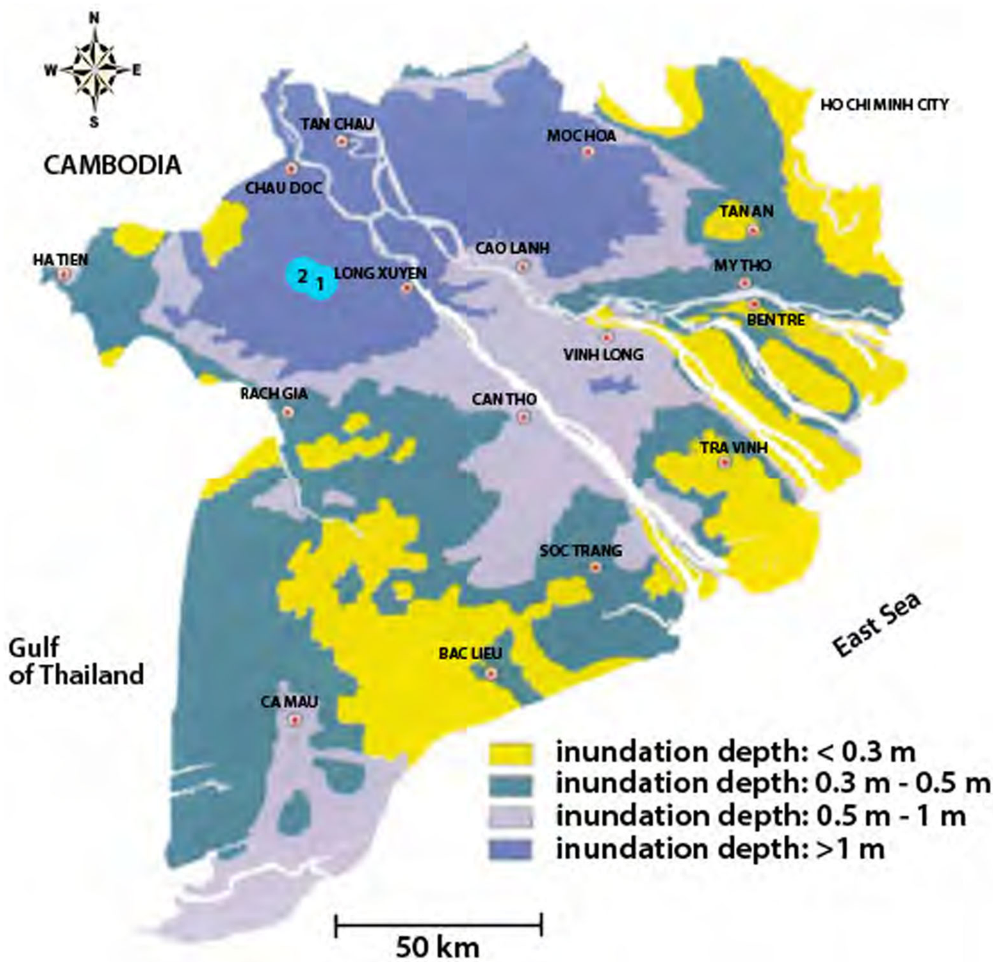

Figure 2. Map of the study site (*Source of base map*: Vo and Matsui 1998).
Notes: (1) The intensive cropping site (Thoai Son district, An Giang province); (2) The contiguous balanced cropping site (Chau Thanh district, An Giang province).

Table 1. Some characteristics of Chau Thanh, Thoai Son in 2012.

	Intensive cropping / high dyke area (Thoai Son)	Balanced cropping / low dyke area (Chau Thanh)
Total land area of district (ha)	46,886	35,506
Population size	181,194	170,817
Population in rural areas	137,592	146,325
Area of rice fields (ha)	39,299	29,222
Rice crops per year	3	2
Yield of rice (tonne per ha)	6.47	6.31

Source: An Giang Statistical Yearbook 2012 (AGGSO 2012).

and natural conditions, such as soil fertility. Intensive cropping has been pursued in Thoai Son district for more than 10 years. This period is long enough to reflect the cumulative effects on rice productivity which resulting from the use of intensive cropping. Under intensive cropping, the first rice crop is grown from mid-December to mid-March, the second from mid-April to mid-July and the third from mid-August to late November. For the balanced cropping sites, the first crop is grown from early December to early March, the second from early April to early July.

3.3.2. Field survey

At each study site, 120 rice-producing households were randomly selected from the list of rice farmers provided by the communal authority. They were then interviewed using a questionnaire which was for detailed household level information pertaining to inputs, costs, and benefits of rice production. This provided 110, 99 usable questionnaires for intensive cropping and contiguous balanced cropping Thoai Son and Chau Thanh, respectively. The survey was conducted for the rice cultivation period lasting from November 2011 to October 2012. Additional information was also collected at agricultural extension offices, and plant protection stations in An Giang and Dong Thap provinces.

4. Results

4.1. Impacts of dyke heightening on rice profit and external costs

4.1.1. Results of rice profit model

On average, farmers employing balanced cropping utilised the same amount of land as farmers using intensive cropping and achieved 6.97 tonnes of rice output per hectare from the first and second crops. Employing the different cropping systems, however, imply the farmers in the two areas incurred different average prices per average unit amount of inputs (Table 2). Regarding farm-specific variables, it was found that the soil of the intensive farming system is less fertile and this system suffers more crop diseases. With one more rice crop, intensive farmers also earn a lower share of non-agricultural income than their balanced neighbours.

Table 2 summarises the estimated translog profit function model used in this analysis.

The coefficient of the dyke heightening dummy was negative ($P < 0.1$) confirming that dyke heightening reduced the profitability of rice production in the high-dyke areas. The estimated profit from intensive cropping, after the influences of other factors were eliminated, was approximately VND 14,075 thousand, and about VND 17,949 thousand from balanced cropping. This reduction in profit is hence calculated to be VND 3874 thousand per hectare per crop for the each of the first two crops or VND 7748 thousand per hectare per year. This was the profit loss incurred by intensive rice farmers in the high-dyke areas in 2012, after ten years of following the current MDDP. This is a 21.6 per cent profit loss of the first two crops.

4.1.2. Results of cost-transfer method (PEA)

Table 4 confirms the increase in pesticide-use externalities since intensive farming applies significantly high in the amount of active ingredients of pesticide per crop and also apply pesticide for one more crop. In total, the increase in the external costs of pesticide use in 2012 due to dyke heightening was VND 204 thousand per hectare. Table 5 suggests that it is farm workers, rather than consumers, who are most at risk from pesticides.

Table 2. Descriptive statistics of the variables used in the rice profit models.

Variable	Low-dyke area	High-dyke area	*t*-ratio	Whole sample
Output, profits, and prices				
Rice output (t)	6.95 (0.84)	6.99 (0.81)	−0.39	6.97 (0.82)
Rice price ('000 VND/t)	5,318.78 (557.98)	4,406.01 (526.87)	12.16***	4,838.38 (707.72)
Fertilizers price ('000 VND/kg)	11.36 (1.31)	11.90 (1.62)	−2.63***	11.64 (1.50)
Labour wage ('000 VND/day)	81.34 (62.42)	98.37 (97.43)	−1.48**	90.30 (82.97)
Machine power price ('000 VND/ha)	5,145.02 (1580.58)	4,407.41 (1,099.34)	3.94***	4,756.80 (1395.23)
Seed price ('000 VND/kg)	13.01 (1.67)	9.52 (4.28)	7.58***	11.17 (3.73)
Pesticide price ('000 VND/kg of active ingredients)	1,490.56 (452.29)	1,365.05 (586.28)	1.71***	1424.50 (529.58)
Land cultivated (ha)	1.93 (1.74)	2.02 (1.53)	−0.39	1.97 (1.63)
Number of working age labour in family (persons)	3.38 (1.53)	3.85 (1.78)	−1.94***	3.62 (1.67)
Farm-specific variables				
Age (years)	44.17 (11.72)	44.09 (10.51)	0.05	44.12 (11.07)
Gender (male = 1, female = 0)	0.96 (0.17)	0.97 (0.16)	−0.13ψ	0.97 (0.16)
Education (years)	6.21 (3.05)	6.07 (3.16)	0.30	6.14 (3.10)
Farm-specific variables				
Training (training = 1, otherwise = 0)	0.31 (0.46)	0.27 (0.44)	0.67ψ	0.29 (0.45)
Soil rank (fertile soil = 1, otherwise = 0)	0.90 (0.29)	0.77 (0.42)	2.60***ψ	0.83 (0.36)
Disease (disease = 1, otherwise = 0)	0.54 (0.50)	0.71 (0.45)	−2.59***ψ	0.63 (0.48)
Non-agricultural income share out of total	0.17 (0.19)	0.08 (0.15)	2.13**ψ	0.12 (0.18)
MDDP effect (intensive cropping in high dykes = 1, balanced cropping in low dykes = 0)	0	1		0.52 (0.5)
Number of observations	99	110		209

Notes: (1) ***, **, * indicate statistical significance at 1%, 5%, and 1% levels, respectively, using *t*-test for comparing means; (2) ψ = Z-ratio for two group test of proportions; (3) SD indicates standard deviation; (4) The Wilconxon rank-sum test was used to compare medians; it shows the same results except for labour wage. Labour wage shows no statistical significance at the 1per cent significance level using Wilconxon rank-sum test; (5) All variables are averages of all farmers' profits from the first and second crops, excluding the third crop, to make the estimates comparable between the two cropping systems.

4.2. Estimation of costs and benefits

4.2.1. Some baseline assumptions

Some assumptions based on the specific features of this case study are presented below.

1. For simplicity, the benefits of high dykes are estimated once the dyke system is fully operational. With respect Todyke heightening, all of the different structures of the irrigation system (e.g. canals, culverts, low and high dykes, pump station) are important because they are connected to one another. Any break in closing the integrated system would eventually damage the crops. Thus, calculating the benefits of the incomplete high dykes during the construction period hence is complex and is ignored here. To ensure the estimates of such benefits are not under-valued, the author assumed that the completed high-dyke system is able to attain its full lifespan. In reality, part of the high dyke system was already significantly degraded by its completion time due to long, 12 years, period of construction.
2. It was assumed that the high dyke system would have a lifespan of 15 years. Farmers would then enjoy the benefits gained from planting the third crop within this 15-year period. This high dyke lifespan was selected based on the advice of the Vice Head of the Department of Irrigation during a personal interview with the author's

Table 3. OLS regression of the rice profit function.

Variables	Coefficient	Robust standard error
ln(normalised price of fertiliser)	0.089	0.239
ln(normalised price of labour wage)	−0.162*	0.096
ln(normalised price of machine power)	−0.660***	0.179
ln(normalised price of seed)	−0.330**	0.162
ln(normalised price of pesticide)	−0.144	0.128
1/2ln(normalised price of fertiliser)^2	0.917	1.058
1/2ln(normalised price of labour wage)^2	0.373*	0.220
1/2ln(normalised price of machine power)^2	−1.685**	0.735
1/2ln(normalised price of seed)^2	−0.232	0.514
1/2ln(normalised price of pesticide)^2	−0.755**	0.342
ln(normalised price of fertiliser) × ln(normalised price of labour wage)	0.066	0.474
ln(normalised price of fertiliser) × ln(normalised price of machine power)	−1.019	0.717
ln(normalised price of fertiliser) × ln(normalised price of seed)	0.267	0.452
ln(normalised price of fertiliser) × ln(normalised price of pesticide)	0.003	0.505
ln(normalised price of labour wage) × ln(normalised price of machine power)	0.028	0.435
ln(normalised price of labour wage) × ln(normalised price of seed)	0.031	0.264
ln(normalised price of labour wage) × ln(normalised price of pesticide)	−0.105	0.206
ln(normalised price of machine power) × ln(normalised price of seed)	0.044	0.436
ln(normalised price of machine power) × ln(normalised price of pesticide)	0.574	0.523
ln(normalised price of seed) × ln(normalised price of pesticide)	−0.229	0.262
ln(normalised price of fertiliser) × ln(land cultivated area)	0.184	0.288
ln(normalised price of fertiliser) × ln(number of working age labour)	0.108	0.367
ln(normalised price of labour wage) × ln(land cultivated area)	0.239	0.170
ln(normalised price of labour wage) × ln(number of working age labour)	−0.061	0.222
ln(normalised price of machine power) × ln(land cultivated area)	0.388	0.310
ln(normalised price of machine power) × ln(number of working age labour)	−0.023	0.291
ln(normalised price of seed) × ln(land cultivated area)	0.177	0.239
ln(normalised price of seed) × ln(number of working age labour)	0.160	0.287
ln(normalised price of pesticide) × ln(land cultivated area)	−0.005	0.133
ln(normalised price of pesticide) × ln(number of working age labour)	0.204	0.200
ln(land cultivated area)	−0.017	0.054
ln(number of working age labour)	0.025	0.075
1/2ln(land cultivated area)^2	0.019	0.093
1/2ln(number of working age labour)^2	0.151	0.251
ln(land cultivated area) × ln(number of working age labour)	0.055	0.099
Age	−0.006*	0.003
Gender	−0.003	0.128
Education	−0.014	0.011
Training	0.124	0.081
Soil Rank	0.226**	0.105
Disease	−0.090	0.066
Off farmshare	−0.251	0.255
Dyke heightening	−0.243*	0.133
Constant	1.596***	0.264
R-squared	0.48	
Included observation	190	

Notes: ***, **, * indicate statistical significance levels at the 1%, 5% and 10% levels, respectively.

research team. To the author's knowledge, there is no document available that cites the lifespan of an earth river dyke. It should be noticed that the first year of 15-year lifespan starts at the last year of 12-year construction period. Accordingly, the project life of heightened dykes is 26 years. In An Giang province, the government started to construct the high-dyke system in 2001. Figure 3 illustrates the pattern of benefits and costs of the intensification project over its 26-year-time horizon from project initiation to complete decline.

3. Family labour cost was included in production costs and assumed to be valued at half the market wage. Rice production is a labour intensive activity. Hence, if

Table 4. Average volume, environmental impact, and external cost of pesticide use, by crop and cropping system.

Crop		Amount of AI (kg per hectare)		Amount of AI (kg per hectare), excluding molluscicides		EIQ (average field-use rating per hectare)		EC (thousand per hectare)	
		High dyke	Low dyke	High dyke	Low dyke	High dyke	Low dyke	High dyke	Low dyke
1st crop	Mean	4.81[a]	7.50[b]	3.29[a]	2.58[b]	36.904	35.721	148	122
	SD	3.21	5.43	2.31	1.36	34.056	57.091		
2nd crop	Mean	4.86[a]	7.67[b]	3.31[a]	2.50[b]	38.028	36.069	155	124
	SD	3.22	5.43	2.31	1.12	34.891	56.971		
3rd crop	Mean	4.97	N/A	3.28	N/A	37.197	N/A	151	N/A
	SD	3.20		2.34		34.960			

Notes: (1) Means that do not share the same subscript letter are significantly different ($P < 0.05$); (2) AI = active ingredients; SD = standard deviation; N/A = not applicable.

Table 5. External costs of pesticide use per hectare, by the EIQ category.

EIQ category	External costs: Unit: thousand VND per hectare per crop	External costs: Unit: per cent
Total farm worker health	**111**	**82.1**
Applicator effects	65	48.1
Picker effects	46	34.1
Total consumer health	**16**	**11.7**
Consumer effects	12	8.9
Ground water	4	2.8
Total environment	**8**	**6.2**
Aquatic effects	5	3.7
Bird effects	1	0.8
Bee effects	1	0.7
Beneficial insect effects	1	0.9
Total	**136**	**100.0**

the cost of family labour is factored into the CBA calculation at current market prices, then estimated rice profit is reduced by one third. Clearly there is a need to take into account for this significant component of costs so as not to overestimate the actual benefit of dyke heightening. However, because the opportunity value of labour may be low, the author valued the cost of family labour at only half its market wage.

4. Over the course of the 15-year lifespan over which net positive benefits were provided from the high dyke, it was assumed that the profit gained from the third crop would be subject to an initial loss of 21.6 per cent in 2012. In the subsequent years, a further 2.3 per cent reduction is added each year. This assumption was made based on our results regarding the rice profit loss of 21.6 per cent due to dyke heightening (see Section 4.1.1 for further detail). This was the profit loss incurred by rice farmers in the high-dyke areas in the year 2012 alone, following the 10-year operation of the high dyke system. As mentioned, these profit losses are cumulative over time as other environmental problems usually are. Hence, a 10-year cumulative loss of 21.6 per cent after long-term operation implies a profit reduction at constant rate of 2.3 per cent per year. As a result, the initial 21.6 per cent reduction and additional 2.3 per cent reduction rates were provisionally assumed through the course of the dyke lifespan. The

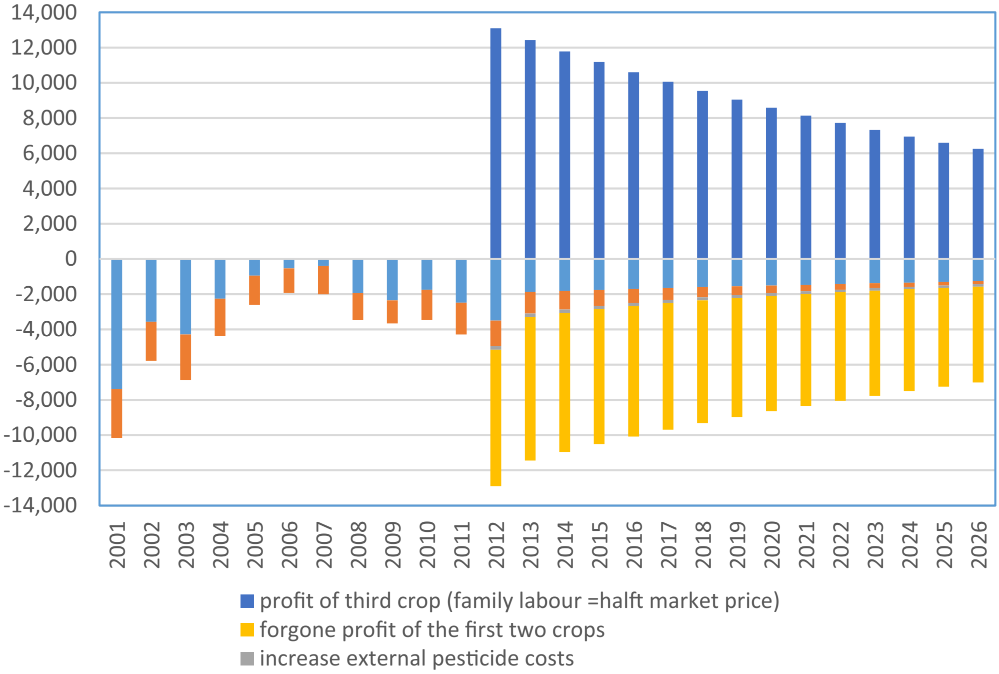

Figure 3. Timing of costs and benefits of dyke heightening.

hypothesis of an additional 2.3 per cent each year will be excluded in a subsequent sensitivity analysis.

5. To estimate the value of fish stocks lost due to high dykes, we need to speculate on the fish prices that might be expected during the coming 2013–2026 period. The domestic demand for fish is expected to increase rapidly up to 2030 due to population growth and to rising real incomes (Brakel, Hambrey, and Bunting 2011) whereas fish supply is likely to decrease as mentioned. However, there is no specific evidence base for how fish prices might change. Therefore, we assumed that fish prices from 2013 to 2026 would remain constant at 2012 price. This is a conservative assumption in the sense that it plausibly downplays the value of fish stocks lost due to high dykes.
6. Based on the results calculated confirming the increase in external cost per crop due to dyke heightening for the 2012 crop (as shown in Section 4.1.2). In subsequent years, these costs would likely increase. However, for the sake of simplicity and because we have no data on such cumulative effects, it was assumed that these increased external costs of pesticide use in the high-dyke areas remain stable at that given level.
7. Also, we assumed the same 2012 dyke maintenance and management costs each year for the entire 15-benefit years.
8. With regard to the choice of discount rate, the UK Treasury has recommended a 3.5 per cent for public sector projects in developed countries which are under 30 years in duration (HM Treasury 2003). On the other hand, the rate could be as high as 10–12 per cent in developing countries (IPCC 2007). Such rates of discount in developing countries are high since the opportunity cost of capital is considered

to be high in these countries (James and Francisco 2015). In practice, various discount rates have been used for CBA studies of natural resource management in Vietnam. For example, discount rates of 3 and 6 per cent were used in the study of sea dykes in Vietnam by Danh and Khai (2014). In the optimisation model of forest management in Nghiem's study, discount rates of 1 to 8 per cent are simulated (cited by James and Francisco 2015). Nguyen (2013) chooses 10 per cent to analyse the economic values of shrimp farming and mangrove conservation in Ca Mau province. The World Bank even uses a discount rate as high as 12 per cent to assess a mangrove rehabilitation project in Ca Mau province (WorldBank 2008). We choose a low discount rate of 3 per cent for this study. The effect of discounting is particularly to promote the importance of benefits and costs that accrue in the future (James and Francisco 2015). The main benefits in our study are in the future whereas most of the costs spent in the initiation through the course of project. Consequently, choosing this low discount rate for developing the basic results in this chapter implies that these results are conservative in the sense that they are not discriminating strongly against future benefits. Increasing the discount rate will increase any assessed economic inefficiency of the dyke-heightening project.

9. This chapter applied the GDP deflator provided by the World Bank (WorldBank 2013d) to convert benefits and costs in different years to base year values in 2012. The GDP deflator (GDPD) is the ratio of nominal GDP to real GDP (Blanchard and Sheen 2004). The values of GDPD from 2000 to 2012 were obtained from the (WorldBank 2013d) database. In addition, the exchange rate in 2012 is used to convert Vietnamese currency to US dollars so US$1.00 equal to VND 20,828 (WorldBank 2013a).
10. As noted, these assumptions mentioned above imply considerable measurement uncertainty. What counts in practice is whether variation of these assumptions in the subsequent sensitivity analysis significantly alters the result. Accordingly, the sensitivity of our results to the assumed family labour cost at half its marketwage, to the assumption that the rate profit declines at 2.3 per cent each year, to the assumed choice of discount rate at 3 per cent and to the assumed 15-year dyke lifespan on our CBA conclusions will be tested and discussed using sensitivity analysis.

4.2.2. Summary of benefits and costs and their calculation process

The following table presents the estimated costs and benefits. Further details of some of them are mentioned in Appendix B.

4.3. CBA results

4.3.1. Defining various stakeholders and the social and private sectors

We conduct CBA of dyke heightening from both the social and from narrower private perspectives. There are different stakeholders involved in this case study. As mentioned, balanced cropping system consists of two rice crops plus one fish crop which naturally moves to the rice field during the flood season. The fish crop is a 'free-ride' crop for all fishers, not necessarily for the farmers who own those rice fields. Hence, fishers are involved. Society were also shown to be affected, for example, due to the increase in pesticide-externalities. Thus the stakeholders involved in this dyke heightening case study include intensive cropping farmers, fishers, other local people in the same province and finally other Vietnamese people.

The social perspective here refers to the Vietnamese society as a whole, hence including all the previously mentioned groups. The private sector refers to only the affected groups at a local place (An Giang province).

4.3.2. Social and private CBA results

The CBA findings broadly pointed to the MDDP's economic inefficiency. Also, this article provides additional insight into the monetary impacts from the perspectives of both the social and private sectors. We show that that dyke heightening has caused society to lose VND 7165 billion (US$344 million) (Table 6). An Giang province alone also lost VND 816 billion (US$39 million) from this project (Table 7). It is

Table 6. Summary of estimated costs and benefits.

Item	Clarification the calculation process	Value estimated in 2012 alone (thousand VND per ha)	Present value estimated for whole dyke project (2001–2026) (thousand VND per ha)
Benefits due to dyke heightening	Equivalent to economic profits gained from the third crops that would have been possible due to the high dykes from 15 benefit years. Based on the third crop's profit in 2012 to speculate for project period	13,099 *(with family labour costs at half the market wage)*	139,311
Costs due to forgone profit from the first two crops	Equivalent to the fall in profits from the first two crops during 15 benefit years in the high-dyke area. Based on the profit lost from the first two crops in 2012 obtained from profit function to speculate for project period.	7748	101,626
Costs due to increase in pesticide's external costs	Equivalent to increase in pesticide's external costs from 15 benefit years in high-dyke area. Based on the increase in external costs of pesticide use in 2012 obtained from PEA tool to speculate for project period.	204	2508
Costs due to forgone net revenues from harvesting natural fish crop	Equivalent to the value of fish in the rice field that would have been harvested if the high dyke was not built at all in 2001. Based on secondary data for project period	N/A	29,919
Infrastructure costs include construction, maintenance, and management costs	Construction costs: equivalent to construction costs that were incurred from 2001 to 2012 (construction period). Based on secondary data to speculate for project period.	N/A	29,489
	Maintenance costs: equivalent to the difference between the maintenance costs of high dykes versus low dykes during benefit years. Based on secondary data in 2012 to speculate for project period	1,247	15,333
	Management costs: equivalent to management costs per hectare of the province since not possible to separate these costs of the high dykes from the low dykes. Based on secondary data in 2012 to speculate total present value for project period.	667.5	8,201

Table 7. Social benefits of dyke heightening in An Giang province, Vietnam.

Category	Estimated values	Present value (thousand VND/ha)
Benefits	Profit from the third crop in high-dyke areas	139,311
Costs	Decrease in profit from the first and second crops	101,626
	Construction costs	29,489
	Maintenance costs	15,333
	Management costs	8,201
	Cost due to foregone revenues from floodplain fishery	29,919
	Increase in external costs of pesticide use	2508
Total net benefits (thousand VND/ha)		−47,767
Total net benefits (US$/ha)		−2293
Total net benefits (billion VND/whole province)		−7165
Total net benefits (million US$/whole province)		−344

Notes: (1) Base year = 2012; (2) Discount rate = 3%; (3) high dyke area in An Giang province is 150 thousand hectares.

Table 8. Private sector benefits of dyke heightening in An Giang province, Vietnam.

Category	Estimated values	Affected groups	Present value (thousand VND per ha)
Benefits	Profit from the third crop in high-dyke areas	Intensive crop farmers	139,311
Costs	Decrease in profit from first and second crops	Intensive crop farmers	101,626
	Construction cost	Intensive crop farmers	8847
	Maintenance cost	Intensive crop farmers	2300
	Value of foregone revenues from floodplain fishery	Fishers	29,919
	Increase in external costs of pesticide use	Intensive crop farmers	2057
Net benefits of intensive crop farmers (thousand VND/ha)			24,481
Net benefits of fishers (thousand VND/ha)			−29,919
Total net benefits (thousand VND/ha)			−5439
Total net benefits (US$/ha)			−261
Total net benefits (billion VND/whole province)			−816
Total net benefits (million US$/whole province)			−39

Notes: (1) Base year = 2012; (2) Discount rate = 3%; (3) high dyke area in An Giang province is 150 thousand hectares.

equivalent to more than one-third of the provincial GDP in 2012 (AGGSO 2013) and hence is a major cost.

It should be noted that the PEA allows us to internalise the external costs of pesticide use in intensive farmers in calculating private result. The external costs of intensive farmers is equivalent to 111 thousand VND per hectare in 2012 crop (Table 5), make it 2057 during the whole project. We here ignored the external costs that imposed on local people since it is not clear how to separate them from other Vietnamese in general. Consequently, with regard to the perspectives of each local group, intensive cropping farmers receive only a very low positive net benefit from dyke heightening when they cultivate the third crop. Meanwhile, fishing people are disadvantaged by dyke heightening and the disadvantages to this group exceeds the advantages to the intensive farmers (Table 8).

Taking into account the uncertainty with respect to the various assumptions made, sensitivity analyses showed the high robustness of our CBA conclusions. Figure 4 confirms the economic inefficiency of dyke heightening over a largely plausible range of discount rates.

Figure 4. CBA calculation at discount rates 3, 6 and 10 per cent from social (a) and private (b) sector perspectives *(Unit: thousand VND).*

Table 9. Social net benefits and private net benefits after relaxing different assumptions.

Category	Discount rate	Social net benefits (Present Value thousand VND/ha)	Private net benefits (Present Value thousand VND/ha)
Base-case assumptions	3	––47,767	–5,439
	6	–58,362	–14,823
	10	–77,338	–28,881
Changes in reduction rate of rice profit to a sustained 21.6 per cent per year (instead adding incrementally 2.3 per cent reduction each year to that 21.6 per cent to reflect the fact that environmental problems are cumulative over time)	3	–19,834	22,495
	6	–36,549	6,991
	10	–62,250	–13,793
Changes in valuing family labour costs at market wage (instead valuing at half of the market wage)	3	–75,100	–32,771
	6	–81,523	–37,984
	10	–96,440	–47,983
Changes in life dyke to 20 years (instead assumed 15 years)	3	–52,791	–5,123
	6	–61,436	–14,610
	10	–78,972	–28,754

Our conclusions are also highly robust after relaxing the base-line assumptions regarding the rate of decrease through time of rice profits, the choice of the price used in valuing family labour costs and the assumed lifespan of high dykes (Table 9).

4.4. Benefits and costs not estimated in the study

This study only estimated total net benefits based on currently available data. It did not consider the following benefits and costs:

Benefits: (1) reduced risk in using high dykes of low dyke overtopping creating damages or losses of houses and people's lives; (2) reduced risk in using high dykes of low dyke overtopping' creating damages or losses of crops, particularly the second crops; (3) benefits from the use of high dykes as roads for transportation.

Costs: (1) newly created risks of high dykes being breached creating damages or losses of houses, people's lives; (2) newly created risks in high dyke breaching creating damages or losses of crops, particularly the third crops; (3) increased external costs from increased fertiliser use; (4) increased flood damage from displacing the flood in downstream areas; (5) decreases in groundwater water retention capacity and recharge; (6) increases in the duration and extent of saline intrusion in the lower delta during dry season; (7) increases in dredging costs caused by deposition in the canals and estuaries; and (8) increases in maintenance cost caused by the increase in flow velocity and the collapse of river banks.

However, this study maintains that the CBA conclusions are not affected by these considerations for the following reasons.

4.4.2. Unaccounted benefits numbered 1 are likely small

In terms of houses and people's lives, there is such little damage in normal flood years since most roads and homes are built on naturally or artificially elevated lands in the floodplain area of the VMD. Also, life in the floodplain of the VMD is well adapted to normal annual floods (IUCN 2011).

4.4.3. There is a trade-off between the unaccounted benefits numbered 1, 2 and the unaccounted costs numbered 1, 2

Dyke heightening also creates new risks in damaging houses, people's lives and for the third crops (costs 1 and 2). Consequently, even though the benefits 1 and 2 were not included in the analysis, they are likely to be offset by the costs 1 and 2 which are also not included.

The possibility of a newly-created big loss due to high dyke breaching, for example, was illustrated in An Giang province during the major flooding in 2011 (Appendix C).

4.4.4. The unaccounted costs numbered 3–8 plausibly outweigh the unaccounted benefit numbered 3

As Sparks (1995) noted on the role of floodplain and its flood pulse, if high levees are maintained, then the floodplain cannot fulfill its hydrologic function of conveying and storing major floods; thus, flood heights and damages are simply increased elsewhere. This argument has been supported by the fact that some of the above costs have not occurred in the high dyke areas.

All of these costs point toward even larger social costs due to dyke heightening. Compared to the transportation benefit that has not been considered, these numerous costs would seem substantial.

5. Conclusion and final remarks

This article has determined the impacts of dyke heightening on agrarian economic activity in the VMD floodplain using cost-benefit analysis. The findings broadly pointed to the MDDP's economic inefficiency. Also, this chapter provides additional insight into the monetary impacts from the perspectives of both the social and private sectors. We show that that dyke heightening has caused society to lose VND 7,165 billion (US$344 million). An Giang province alone also lost VND 816 billion (US$39 million) from this project. It is equivalent to more than one-third of the provincial GDP in 2012 (AGGSO 2013) and hence is a major cost. Taking into account the uncertainty with respect to the various assumptions made, sensitivity analyses showed the high robustness of our CBA conclusions.

With regard to the costs of dyke heightening, this study was limited in quantifying four main items. Among them, the CBA demonstrated that the decrease in profit from the first and second crops was the main cost of dyke heightening. The second and third largest costs were the infrastructure cost of the dykes and the foregone revenues from the floodplain fishery. The increase in pesticide-use external cost was the smallest cost out of total estimated costs of dyke heightening and was not, in fact, significant. The infrastructure costs—which are straightforward and well recognised—are not easy to access. The other three costs are largely ignored and not mentioned in official reports that discuss the case for high dykes.

With regard to the perspectives of each local group, intensive cropping farmers receive only a very low positive net benefit from dyke heightening when they cultivate the third crop. If they choose not to follow intensive cropping, they will further under-perform. Meanwhile, fishing people and the other local people, in general, are disadvantaged by dyke heightening and the disadvantages to these groups exceed the advantages to the intensive farmers.

The CBA results create real doubts about the case for further heightening of dykes in the VMD, a process that is still in progress. As noted, heightening has yielded a substantial monetary loss in An Giang province due to the effects of the high dykes. This is compelling information that has not typically been made available to policy makers in these areas. These insights can be used to form more sensible agro-economic policies that do not rely on high dykes. In addition, this study calls for the attention of the policy makers in protecting disadvantaged stakeholders in the areas where high dykes are to be constructed. One example of possible measures can be supporting fishers, the most disadvantaged group, in looking for new jobs or new sources of income since their income were lost by the project. Another measure can be promoting technological advances in agriculture so that farmers are able to maintain rice profitability in the face of unfavourable conditions in the high-dyke areas.

Although it is beyond the scope of this study, it can be remarked that the government may limit the negative impacts of dyke heightening by improving the design and management of the existing high dykes such that the structure would allow floodwater to flow into the floodplain. The intended design of the high dykes in VMD allows the flood to come inside the high dykes every two years. However, this was not implemented due to improper design and management failures. In the course of conducting the survey, we recognised that local farmers and authorities have been increasingly becoming aware of the need to allow the flood to flow naturally. This helps improve soil quality in the fields and helps release some of the environmental stress placed by the cumulative effects of numerous human activities (e.g. increased agro-chemical pollution inside high dykes). However, implementing these changes would be challenging—the local people have already adapted to the permanent "no-flood" condition inside the high dykes. Thus, to allow flooding would entail new costs.

In the meantime, the VMD is still strongly following a development trajectory associated with large-scale water control infrastructures such as high dykes. Our argument is that economic efficiency considerations do not provide a rationale for this development trajectory.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix A: Illustration of the steps used to calculate the external cost of pesticide use for a farming system

Based on the PEA model, we calculate the so-called total external cost (TEC) for a farming system as follows:

$$TEC = \sum_{p=1}^{m} \left[A_p * p_{active} * \sum_{c=1}^{8} \left[EC_c * F_c * x\left(F_{agemp} | c = 1, 2\right) \right] * F_{gdppc} \right] \quad \text{(Eq. 1)}$$

where:
A_p: application rate (kg/hectare) of a pesticide p for a total of m pesticides.
p_active: proportion of active ingredients.
EC_c: external cost base values of 1 kg of active ingredient for the average pesticide in EIQ categories.

F_c: toxicity level of pesticide (0.5 = relatively low level of toxicity, 1.0 = medium toxicity, and 1.5 = highly toxic).

c: category c of the eight categories that were evaluated in developing the EIQ model.

F_{agemp}: ratio of Mekong Delta's share of employment in agriculture to the average share of agricultural employment in Germany, the UK, and US (weighted by GDP).

F_{gdpc}: ratio of Vietnam's per capita GDP to average per capita GDP in Germany, the UK, and US (weighted by GDP).

For calculating A_p *and p_active*

These are straightforward information to obtain from field trips. The application rate of pesticide p for a total of m pesticides is obtained from field surveys. The proportion of active ingredients in the formulated product is obtained from field surveys of pesticide traders, pesticide shops, and pesticide producers.

For calculating *ECC*

There are several steps. The estimates of ECC are shown in Table A3.

Step 1: Convert the value of the external cost (EC) of 1 kg of active ingredient for the average pesticide as estimated in the three countries to 2012 VND values

The mean cost per kg active ingredient from each category is the mean value of the three countries.

Step 2: Redistribute the external cost categories by Pretty et al. (2000) to the EIQ categories (Kovach et al. 1992)

The PEA model provides proportional distribution to integrate external costs and EIQ systems: See Table A2. Using this provided ratio in Table A2 and the average per kilogram active ingredient external cost categories in Table A1, we obtain Table A3.

The PEA model converts EIQ vales for each of eight EIQ categories to external costs by multiplying the external cost base values with a factor Fc. This factor F_c takes levels 0.5, 1.0 and 1.5 for low, medium and high level of toxicity. For each category, we follow the low, medium and high toxicity ranges defined by Leach and Mumford (2008): See Table A4. Assigning EIQ values to F_c implies that when data for a real pesticide are put into the model, the average active ingredient per kilogram costs for each EIQ category are applied at half, unchanged or one-and-a-half times the costs for low, medium and high classification respectively. An example of estimated Fc for one pesticide is shown in Table A5.

For calculating the economic adjustment factors (F_{agemp}, F_{gdpc})

The values of F_{agemp}, $F_{gdpc}$are shown in Table A6. Some explanations on calculating these factors are as follows.

F_{agemp} is a ratio of the Mekong Delta's share of employment in agriculture to the average share of agricultural employment in Germany, the UK and the US, weighted by GDP. Leach

Table A1. Conversion of the external cost of 1 kg of an average pesticide by Pretty et al. (2000) to 2012 VND values.

Categories in Pretty et al. (2000)	Mean cost per kg a.i. (Euros at 2005 rates) EC	Mean cost per kg a.i (VND in 2012 year) EC
1. Contamination of drinking water	5.6	238,249.57
2. Pollution incidents, fish death, monitoring	0.81	34,461.10
3. Biodiversity/wildlife losses	0.52	22,123.17
4. Cultural, landscape, tourism, etc.	1.33	56,584.27
5. Bee colony losses	0.13	5,530.79
6. Acute effects to human	0.39	16,592.38
Total external costs	8.78	373,541.29

Source: (Leach and Mumford 2008) and converted to 2012 VND values by author.
Note: EC = external cost as estimated by Pretty et al. (2000) and converted to 2012 VND values using the consumer price index of Vietnam.
Average exchange rate in 2005 between VND and EURO was 19.692 VND/EURO. Vietnam's consumer price index in 2012 was 216.05 per cent (WorldBank 2013b). Hence, total external costs = 8.78 × 216.05/100 × 19.692 = 373,541.29 VND.

Table A2. Ratio distribution to integrate 2 systems: External costs of pesticides system and EIQ system.

Categories in Pretty et al. (2000)	Applicators (1)	Pickers (2)	Consumers (3)	Ground water (4)	Aquatic effects (5)	Birds (6)	Bees (7)	Beneficial Insect (8)
	EIQ categories							
1. Contamination of drinking water	0.1	0.1	0.6	0.1	0.1			
2. Pollution incidents, fish death, monitoring				0.5	0.5			
3. Biodiversity/wild losses					0.3	0.3	0.1	0.3
4. Cultural, landscape, tourism, etc.			0.5			0.2	0.1	0.2
5. Bee colony losses							1.0	
6. Acute effects to human health	0.8	0.15	0.05					

Source: (Leach and Mumford 2008).

Table A3. Distribution of external costs from Pretty et al. (2000) categories to the EIQ system for 1 kg of active ingredient for the average pesticide.

Categories in Pretty et al. (2000)	Applicators (1)	Pickers (2)	Consumers (3)	Ground water (4)	Aquatic effects (5)	Birds (6)	Bees (7)	Beneficial Insect (8)
	EIQ categories							
1. Contamination of drinking water	23,824.96	23,824.96	142,949.74	23,824.96	23,824.96			
2. Pollution incidents, fish death, monitoring				17,230.55	17,230.55			
3. Biodiversity/wild losses					6,636.95	6,636.95	2,212.32	6,636.95
4. Cultural, landscape, tourism, etc.			28,292.14			11,316.85	5,658.43	11,316.85
5. Bee colony losses							5,530.79	
6. Acute effects to human health	13,273.90	2,488.86	829.62					
EC_c	37,098.86	26,313.82	172,071.5	41,055.51	47,692.46	17,953.80	13,401.54	17,953.80

Source: calculated by author.

Table A4. Quotient classification for each EIQ category.

Range of EIQ values	F_c	Applicators	Pickers	Consumers	Ground Water	Aquatic effects	Birds	Bees	Benef. insects
		EIQ categories							
Low risk	0.5	<25	<14	<16	<2	<5	<15	<15	<25
Medium risk	1.0	25–85	14–76	16–55	2–4	5–17	15–51	15–51	25–85
High risk	1.5	>85	>76	>55	>4	>17	>51	>51	>85

Source: (Leach and Mumford 2008).

Table A5. Example of F_c value for one pesticide named Methomyl.

Categories	Applicators	Pickers	Consumers	Ground water	Aquatic effects	Birds	Bees	Benef. insects
	Methomyl							
$EIQ_{p,m}$(*)	5	1	6	5	3	6	15	25
F_c(**)	0.5	0.5	0.5	1.5	0.5	0.5	1.0	1.0

Note: (*) base value of the active ingredients over eight categories of EIQ, obtained from List of pesticides in 2012 (see New York State Integrated Pest Management 2012); (**) classification based on Table 4 and EIQ base values in Table 5.

and Mumford (2008) use the share of agricultural sector in the GDP as a proxy for health-related externalities. We instead choose the share of agricultural labour in total employment, as it better reflects the number of people likely to come into direct contact with pesticides on farms: See Praneetvatakul et al. (2013). The farm workers in EIQ categories are applicators

Table A6. Calculating the economic adjustment factors (source: calculated by author).

adjustment Factor	EIQ categories							
	Applicators	Pickers	Consumers	Ground water	Aquatic effects	Birds	Bees	Benef. insects
F_{agemp}	34.09	34.09	1.0	1.0	1.0	1.0	1.0	1.0
F_{gdppc}	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

and pickers. Therefore, we multiply the external costs for these groups ($c = 1.2$) by F_{agemp}. Vietnam's share of agricultural employment in 2012 was 48.4 per cent (WorldBank 2013c). The average share of agricultural employment in Germany, the UK and the US (weighted by GDP) was 1.42 per cent (Praneetvatakul et al. 2013). The adjustment factor for Vietnam's case hence would be 34.09 for applicators and pickers and 1 for other groups: See Table A6.

F_{gdpc} is a ratio of Vietnam's per capita GDP to average per capita GDP in Germany, the UK and the US again weighted by GDP. In 2012, the Vietnam's per capita GDP in current international dollars (Int.$) was 3,635.21 Int.$and the weighted average per capita GDP for Germany, the UK, and the US was 46,968.78 Int.$ (WorldBank 2013c). The adjustment factor hence is 0.08 as shown in Table A6.

Appendix B: Estimation of benefits and costs

1. Estimation of benefits

This subsection calculates the present value of the benefits due to the dyke-heightening project. The resulting estimates equal the present value of economic profits gained from the 15 third crops that would have been possible due to the high dykes from 2012–2026. As previously discussed, the primary benefit of dyke-heightening is the profits gained from the third crop. The estimated profit of the third crop in 2012 was VND 15,699thousandper hectare. It fell to VND 13,099 thousand per hectare once family labour costs are included at half the market wage in 2012. The present value of the third crop benefits due to dyke heightening through the course of project was thus calculated to be VND 139,311 thousand per hectare or US$6,689 per hectare.

2. Estimation of costs

2.1. Forgone profits from the first two crops

The profit loss from the first two crops in 2012 was estimated to be VND 7,748 thousand per hectare. Accordingly, the present value of the fall in profits from the first and second crops in the high-dyke area due to dyke heightening was estimated to be VND 101,626 thousand per hectare (US$4,879 per hectare).

2.2. Increase in pesticide's environmental/external costs

There are costs arising from dyke heightening due to the increase in pesticide-use externalities. It equates to the differences in those costs between intensive and balanced farming of An Giang. We applied PEA to calculate the environmental impact and associated external cost of pesticide use for each crop of the two systems: see Table B1.

The results can be summarised as follows. First, the external costs of pesticide use in the first and second crops in the high-dyke areas were higher by VND 22 thousand per hectare and VND 31 thousand per hectare, respectively, as compared to those in the low-dyke areas. Second, the external cost of pesticide use in the third crop made possible by the high dykes was VND 151 thousand per hectare. Third and accordingly, in total the increase in the external costs of pesticide use in 2012 due to dyke heightening was VND 204 thousand per hectare. The resulting present value of the increase in these environmental costs of dyke project was then calculated to be VND 2508 thousand per hectare (US$120 per hectare).

Table B1. Average volume, environmental impact, and external cost of pesticide use, by crop and cropping system.

Crop		Amount of AI (kg per hectare)		Amount of AI (kg per hectare) Excluding Molluscicides		EIQ (average field-use rating per hectare)		EC (thousand per hectare)	
		High Dyke	Low Dyke	High Dyke	Low Dyke	High Dyke	Low Dyke	High Dyke	Low Dyke
First crop	Mean	4.81[a]	7.50[b]	3.29[a]	2.58[b]	36.904	35.721	148	122
	SD	3.21	5.43	2.31	1.36	34.056	57.091		
Second crop	Mean	4.86[a]	7.67[b]	3.31[a]	2.50[b]	38.028	36.069	155	124
	SD	3.22	5.43	2.31	1.12	34.891	56.971		
Third crop	Mean	4.97	N/A	3.28	N/A	37.197	N/A	151	N/A
	SD	3.20		2.34		34.960			

Notes: (1) Means that do not share the same subscript letter are significantly different ($P < 0.05$); (2) AI = active ingredients; SD = standard deviation; N/A = not applicable.

Table B2. Value of foregone revenues from floodplain fishery during the construction period.

Year	Loss of fish Yield from Floodplain Fishery (kg/ha) (1)	Value of Fishery Catch (thousand VND/tonne) at current prices (2)	Revenue loss per hectare (thousand VND/ha) (3) = (1)*(2)*1000	GDP Deflator	Revenue loss from floodplain fishery (thousand VND/ha) at 2012 prices	Present value (thousand VND/ha) discount rate = 3%
2001	168	3.81	640	43	2,002	2,771
2002	149	3.73	555	45	1,654	2,223
2003	132	5.39	709	48	1,979	2,582
2004	116	5.67	660	53	1,685	2,135
2005	103	5.58	575	58	1,345	1,654
2006	91	5.94	542	63	1,166	1,392
2007	81	8.75	706	69	1,387	1,608
2008	71	11.94	853	84	1,366	1,537
2009	63	12.51	791	89	1,193	1,303
2010	56	21.46	1,201	100	1,615	1,713
2011	50	31.98	1,584	121	1,756	1,809
2012	44	32.91	1,442	135	1,442	1,442
Total						22,169

2.3. Forgone net revenues from harvesting natural fish crop

This is the cost of dyke heightening due to the loss of natural fish habitat in the floodplain rice fields. It is equivalent to the foregone net revenues from the natural floodplain fishery per hectare due to dyke heightening.

The first stage of the calculation involved estimating the volume of fish in the rice field that would have been harvested if the high dyke was not built at all in 2001. This volume depends on the fish yield on the rice field and the technology for harvesting the fish. There was no data on average fish yields in the floodplains in the year 2001, the starting year of the dyke project. However, data was available for the year 1995. The average fish yield in the floodplains in the southern provinces of Vietnam then was found to be 119 kilograms per hectare (De Graaf and Chinh 2003). Within the period of 1995–2001, Le (2008) reported a significant increase in fish harvesting in the Mekong Delta due to technological developments in the fishery sector. This reflected the development and application of new fishing gear although this had led to more damage being done to natural aquatic resources. Accordingly, there was 40 per cent increase in the volume of captured fish in 2001 compared to 1995 (AGGSO 2006). We, therefore, assumed that the volume of fish in the rice field that would have been harvested in 2001 would be 40 per cent higher than those in 1995 so it would be 169 kilograms per hectare in 2001. To speculate on the volume of fish that would have been harvested without high dykes over the life of dyke heightening project, we further assumed that fish harvest from rice fields at the study sites would have declined by 11.5 per cent per year. This assumption was based on the

Table B3. Consolidated list of dyke system construction works, An Giang province, 2001–2012.

Year	Total works	Number by Structure: Canal	Dyke	Culvert	Pumping station	Field internal irrigation	Total length (m)	Dug and Embanked Amount (m^3)	Area for third rice crop (hectare)	Total Costs (in million VND) (2012 prices)	Present Value (thousand VND/ha) at $r = 3\%$
2001	711	57	286	347	21		1,789,906	11,735,233	18,855	800,674	7,389
2002	555	103	149	230	73		1,316,545	6,614,596	35,352	397,130	3,558
2003	766	142	234	385	5		1,003,931	9,721,564	62,998	492,992	4,288
2004	793	126	125	297	79	166	733,857	4,561,001	80,340	267,175	2,256
2005	501	194	107	163	37		879,879	4,418,332	83,385	115,483	947
2006	548	126	18	140	100	164	606,819	3,135,941	43,152	67,106	534
2007	351	99	32	102	1	117	496,955	3,107,261	58,859	52,058	402
2008	560	52	57	249	202		331,360	3,660,971	94,421	259,271	1,945
2009	673	166	24	206	277		553,940	5,647,703	84,249	323,387	2,356
2010	485	148	238	0	99		949,564	8,774,792	115,037	246,998	1,747
2011	948	324	425	0	199		1,151,000	7,880,000	133,723	361,003	2,479
2012	549	51	244	78	176		614,800	4,963,500	149,542	238,122	1,587
TOTAL	**7,440**	**1,588**	**1,939**	**2,197**	**1,269**	**447**	**10,428,556**	**74,220,894**	**959,913**	**3,621,400**	**29,489**

Source: An Giang Sub-Department of Irrigation (AGSDI 2013) and calculated by author.
Notes: (1) Total expenses are adjusted to 2012 prices using GDP deflators (WorldBank 2013d); (2) Total costs included the costs of building a temporary dam in 2001 (VND 1.49 billion).

speculation of Le (1995) and Le and Nguyen (2000) that an average 10-13 per cent annual decline in fish yield in rice fields for coming years in the VMD. This speculation was supported by Brakel, Hambrey, and Bunting (2011). This latter study stated that the numbers of fish being harvested from the Mekong Delta, specifically in the Lower Mekong Basin, are expected to decline up to 2030. The decline results from overfishing, water pollution, destructing of natural fish habitats in the delta, and the increased pressures from the upstream countries.

The second stage of the estimation involved speculating on the value of those fish. This study used the current prices for one average tonne of fish calculated by AGGSO for the past 2001–2012 period (AGGSO 2006; AGGSO 2013). As mentioned, we assumed that fish prices from 2013 to 2026 would remain constant at 2012 price.

Based on these considerations, the present value of the foregone fishery revenues during the construction period of the high dykes amounted to VND 22,169 thousand per hectare: Table B3. The present value of foregone revenues from floodplain fishery for the period 2013–2026 was estimated to be VND 7,750 thousand per hectare.

In total, the present value of forgone fishery revenues due to dyke heightening was calculated to be VND 29,919 thousand per hectare (US$1,436 per hectare), 74.1 per cent of which would be lost during the construction period.

2.4. Infrastructure costs of dyke heightening

Construction costs

As the low dykes were converted into high ones, the construction costs of high dykes were equivalent to these costs of dyke heightening. The high-dyke system in An Giang province consisted of a series of high dykes with their associated structures such as pumping stations. These were built gradually each year "one piece at a time" during the construction period: See Table B4. The construction costs of the dyke heightening project hence equivalent to those costs that were incurred from 2001 to 2012 (Table B3). The present value of these costs was then estimated to be VND 29,489 thousand per hectare (US$1,416 per hectare).

Data on maintenance costs during the construction phase were not available and so were excluded from this study. Therefore, the increase in maintenance costs of dyke heightening was estimated as the difference between the maintenance costs of high dykes versus low dykes during the subsequent period 2012–2016 when net benefits were being generated. Although the dyke systems at the study sites were made of mud, annual maintenance was required to keep the dykes fully operational for 15 benefit years. According to available data from the

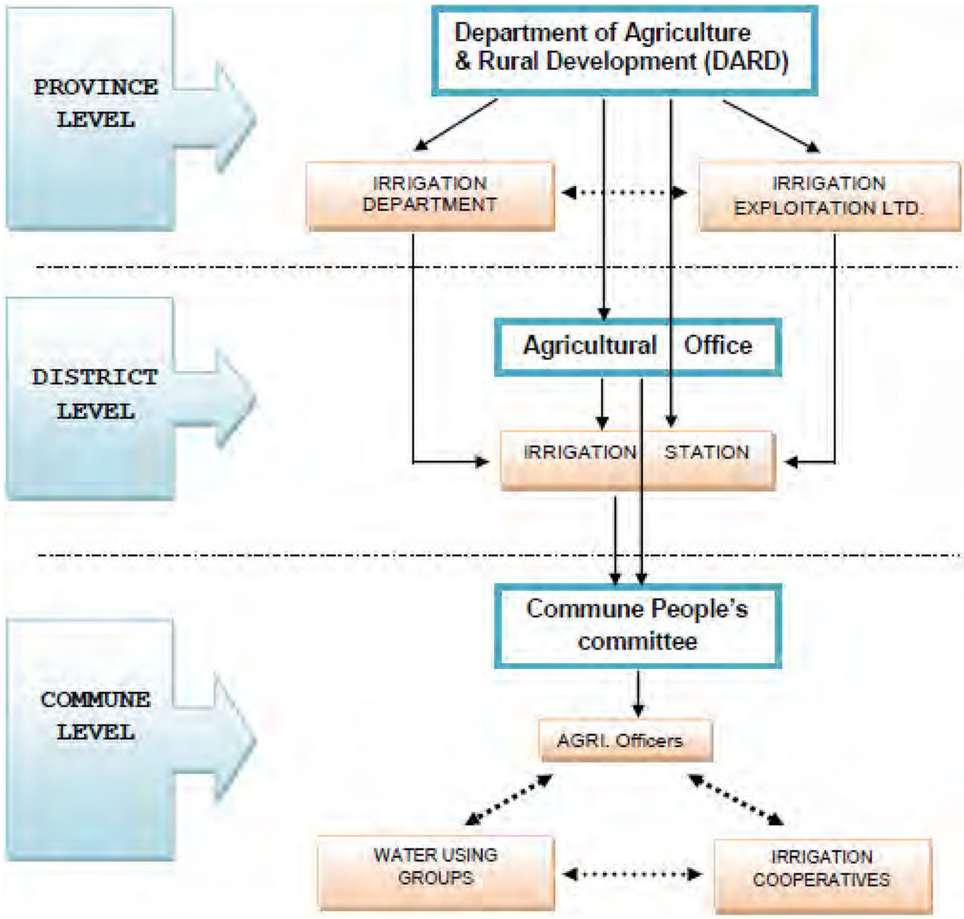

Figure B1. Management system of the dykes, An Giang province.

Department of Irrigation, the maintenance costs in 2012 for the high-dyke system in the 150 thousand-hectare area used for the third crop in An Giang were estimated at VND 194 billion or VND 1,297 thousand per hectare. For the low-dyke area, the maintenance costs in 2012 differed across upstream and downstream areas. Following the annual flood season in 2011, about VND 2–3 billion was spent to maintain the low-dyke system in the 10,000-hectare upstream area. This equates to an average of VND 200 thousand per hectare. Meanwhile, maintenance costs in 2012 in the 40,000-hectare downstream area amounted to VND 2 billion (VND 50 thousand per hectare). In the present study, where dyke heightening is located mainly downstream, we used the costs associated with low dykes in the downstream area to calculate the rise in maintenance cost of dyke heightening. The difference in the maintenance costs for high dykes and low dykes in 2012 was, therefore, VND 1,247 thousand per hectare. This also translates to an increased maintenance costs due to dyke heightening. It was also assumed that during the 15-year benefit phase, the maintenance costs for each year would remain the same. Therefore, the present value of the increase in maintenance costs of the high dyke was calculated to be VND 15,333 thousand per hectare (US$736 per hectare).

Management costs

Along with rapid investment and development of high dykes, the local government responsible for An Giang province also established a management system for the irrigation/high-dyke system at all administrative levels. Dykes are classified into five levels basing on the population

Table B4. Management costs of dyke system in An Giang province, 2012.

Management level	Organisations	Province's budget (million VND)	Budget (VND thousand per hectare)	Note
Provincial level	Irrigation Department	1,200	6.0	Lumpsum budget for 15 personnel
	Irrigation Exploitation Ltd.	7,000	35.0	Lumpsum budget for 65 personnel
District level	District office of Agricultural and Rural Development 11 Irrigation Stations	3,300	16.5	Lump sum budget for one agriculture staff member in the district agriculture office, and five personnel in one irrigation station per district
Commune level	Commune level	2,000	10.0	One commune agriculture staff member per commune
	300 cooperative-group water users	20,000	100.0	Operational costs
	Support to agriculture infrastructure	100,000	500.0	
Total		133,500	667.5	

Note: The province's budget to pay for the dykes' management costs covered 200,000 hectares of dyke area, including 150,000 hectares for the intensive cropping and 50,000 hectares for the balanced cropping.

protected by the infrastructure, the importance of the level of defense, security, socioeconomics, flood and storm characteristics of each region, areas and administrative boundary, average flood depth of residences compared to flood level designed, and designed flood flow (MARD, 2010). Each management level is responsible for managing certain levels of dykes. The management machinery is summarised in Figure B1.

Similarly to the maintenance costs, the data on management costs of the high dykes during the construction phase were not available. Increases in management costs due to dyke heightening were estimated for the subsequent period of net benefits from 2012–2016. The management costs of high dykes were assumed to be equivalent to those concerning the low dykes in An Giang. This was because the management system of irrigation at all administrative levels was established along with, and mainly due to, the rapid investment in and development of high dykes. It was not possible to separate the management costs of the high dykes from the low dykes at the study sites. Moreover, 75 per cent of the land in An Giang is high-dyke areas.

Table B4 summarises that the total budget for managing the dyke systems in An Giang province. In 2012 alone this budget was VND 133.5 billion or VND 667.5 thousand per hectare. As with the calculation of construction and maintenance costs, we assumed the same 2012 dyke management cost each year for the entire 15-benefit years. Accordingly, the present value of the management cost for the high dykes project was VND 8,201 thousand per hectare or US$394 per hectare.

Appendix C: Loss due to dyke breaching was illustrated in An Giang province during the major flooding in 2011

Aside from the hundreds of thousands of people mobilised to provide unpaid work on shifting schedules to save the dykes, the damage cost amounted to VND 72.4 billion (AGCFSC 2011). Using the deflator adjustment, the damage cost at 2012 prices was VND 80.8 billion or VND 404 thousand per hectare where we include both the high-dyke and low-dyke areas of 200 thousand hectares.

Despite the huge budget spent to construct the high dykes in order to protect the third crop, and despite great efforts and human resources spent to maintain the dykes, losses and damage to the third crop cannot be avoided. The agriculture-related flood losses in 2011 indicated more types of damages aside from those to the third crop, compared to those in 2000

Table C1. Agriculture-related flood losses, 2000 and 2011.

No.	Loss	Unit	2000	2011
1	Completely re-sowing area (third crop)	Hectare		4,059
2	Partly re-sowing area (third crop)	Hectare		500
3	Areas requiring drainage pumping (third crop)	Hectare		131,000
4	Loss of rice + upland crop	Hectare	4,947	4,539
5	Flooded third crop rice crop + upland crop	Hectare		1,261
6	Early harvesting second rice crop + upland crop	Hectare	16,911	78
7	Loss of fish production	Tonne	2,478	72
8	Loss of breeding fish	Million		5
9	Pond flooded	Pond		701
10	Completely lost fruit tree area	Hectare		24
11	Flooded husbandry facilities	Facilities		675
12	Dykes broke by flood	Km	1,500	1,000
13	Roads flooded	Km	193	31
14	Rural roads flooded	Km	1,069	144
15	Roads broken	Km		61
16	Land eroded	m^2	363,737	30,803

Source: AGPC (2011).

(Table C1). This may be because of the false sense of security created by high dykes which weakened the people's ability to adapt to the high-dyke areas; when in fact, the risks associated with dyke systems have not been reduced but only transformed due to dyke heightening. What economists refer to as moral hazard can be a severe problem that reduces flood disaster preparedness.

Due to the 2011 flooding incident, more than VND 688 billion of emergency aid was released by the government to: first, protect the 140 thousand-hectare plantation area allotted for the third rice crop; and second, to compensate for the losses in agricultural production. The costs of consolidating the 1050-kilometer high-dyke systems for protecting the third crop alone were more than VND 280 billion (AGPC 2011). Using the deflator adjustment, this aid translates into VND 5483 thousand per hectare at 2012 prices. If only the direct costs of controlling the flood when the dyke broke in 2001 and the required aids were considered in the calculation, the cost of the broken dyke during the 2011 flooding would amount to VND 5,887 thousand per hectare (at 2012 prices).