Environment for Development

Discussion Paper Series

September 2023 ■ EfD DP 23-15

Heterogeneity in Shadow Prices of Water Pollutants

A Study of the Seafood Processing Industry in Vietnam

Pham Khanh Nam, Pham Nhu Man, and Truong Dang Thuy

Central America
Research Program in Economics and Environment for Development in Central America Tropical Agricultural Research and Higher Education Center (CATIE)

Chile
Research Nucleus on Environmental and Natural Resource Economics (NENRE)
Universidad de Concepción

China
Environmental Economics Program in China (EEPC)
Peking University

Colombia
The Research Group on Environmental, Natural Resource and Applied Economics Studies (REES-CEDE), Universidad de los Andes, Colombia

Ethiopia
Environment and Climate Research Center (ECRC), Policy Studies Institute, Addis Ababa, Ethiopia

Ghana
The Environment and Natural Resource Research Unit, Institute of Statistical, Social and Economic Research, University of Ghana, Accra

India
Centre for Research on the Economics of Climate, Food, Energy, and Environment, (CECFEE), at Indian Statistical Institute, New Delhi, India

Kenya
School of Economics
University of Nairobi

Nigeria
Resource and Environmental Policy Research Centre, University of Nigeria, Nsukka

South Africa
Environmental Economics Policy Research Unit (EPRU)
University of Cape Town

Sweden
Environmental Economics Unit
University of Gothenburg

Tanzania
Environment for Development Tanzania
University of Dar es Salaam

Uganda
EfD-Mak, School of Economics and Department of Agribusiness and Natural Resource Economics, Makerere University, Kampala

USA (Washington, DC)
Resources for the Future (RFF)

Vietnam
University of Economics
Ho Chi Minh City, Vietnam

Heterogeneity in Shadow Prices of Water Pollutants: A Study of the Seafood Processing Industry in Vietnam

Pham Khanh Nam[a], Pham Nhu Man[b], and Truong Dang Thuy[c]

Abstract

This study examines the marginal abatement costs (MACs) of three water pollutants (BOD, COD, and TSS) in the seafood processing industry in the Mekong River Delta of Vietnam. Using data on production activities and pollutant concentration, we estimate the MACs and analyze their relationship with firm characteristics. The results reveal significant heterogeneity in MACs, with younger firms, less labor-intensive firms, LLCs and joint-stock companies, firms located in seashore or riverside areas, and those with ISO or other certifications exhibiting lower MACs. These findings suggest that a uniform standard or environmental fee may not efficiently address pollutant reduction. Instead, a tradable permit system could be a more effective approach.

Keywords: seafood, water pollutants, marginal abatement cost, directional distance function

---

[a] School of Economics, University of Economics HCMC,

[b] The Joint Doctorate Programme, University of Economics HCMC and Erasmus University Rotterdam.

[c] School of Economics, University of Economics HCMC, corresponding author, email: truong@dangthuy.net

Acknowledgment: This study is funded by the Swedish International Development Cooperation Agency (SIDA) through the Environment for Development Initiative (EfD) Project number MS-380.

HETEROGENEITY IN SHADOW PRICES OF WATER POLLUTANTS: A STUDY OF THE SEAFOOD PROCESSING INDUSTRY IN VIETNAM

Pham Khanh Nam[(a)], Pham Nhu Man[(b)], Truong Dang Thuy[(c)]

(a) School of Economics, University of Economics HCMC
(b) The Joint Doctorate Programme, University of Economics HCMC and Erasmus University Rotterdam.
(c) School of Economics, University of Economics HCMC, corresponding author, email: truong@dangthuy.net

Abstract

This study examines the marginal abatement costs (MACs) of three water pollutants (BOD, COD, and TSS) in the seafood processing industry in the Mekong River Delta of Vietnam. Using data on production activities and pollutant concentration, we estimate the MACs and analyze their relationship with firm characteristics. The results reveal significant heterogeneity in MACs, with younger firms, less labor-intensive firms, LLCs and joint-stock companies, firms located in seashore or riverside areas, and those with ISO or other certifications exhibiting lower MACs. These findings suggest that a uniform standard or environmental fee may not efficiently address pollutant reduction. Instead, a tradable permit system could be a more effective approach.

Keywords: seafood, water pollutants, marginal abatement cost, directional distance function

Acknowledgement

This study is funded by the Swedish International Development Cooperation Agency (SIDA) through the Environment for Development Initiative (EfD) Project number MS-380.

1. BACKGROUND

Seafood is a large and important sector in Vietnam. The sector accounts for 3.7% of Vietnam's GDP, is the fourth largest in export with a value of $7.1 billion in 2016, and provides over 4 million jobs (VASEP, 2016). However, the sector is under threat from industrial pollution, low productivity, and inefficiency. Most of the 1,300 processing plants (only 567 factories are licensed to export) are small and medium enterprises (SMEs). Over 80% of processed products are frozen, using raw materials, water and energy intensively. The ratio of final product to rest raw materials is extremely high (e.g. 1:1.8 in fish, 1:0.75 in shrimp, & 1:8 in bivalve processing). While large firms can make these rest materials into by-products, SMEs simply release them into the environment. In addition, methods used in recovery of biomolecules from rest raw materials in Vietnam currently are physical separation, inducing low yield, high energy and water consumption, and undesirable and corrosive side products.

Most processing plants are located alongside rivers or seashores, discharging effluents which contain large amounts of organic matter, small particles of flesh, breading, soluble proteins, and carbohydrates, directly into receivers, often without prior treatment (Venugopal and Sasidharan, 2021). Despite the Law on Environmental Protection (LEP) approved in 2014 and 2020. pollutants in the air and ground water and odor in areas surrounding processing plants are at an alarming level of severity (MONRE, 2021).

The current environmental policy framework in Vietnam remains dominated by the application of command-and-control instruments under the LEP. The law sets many standards and rules for pollution control in the seafood processing industry, but often fails to guarantee their effective enforcement. Seafood processing firms, especially among the SMEs, over-discharge pollutants into the environment. The Vietnamese Environmental Protection Agency has considerws an approach that conducts enforcement and monitoring of environmental standards in the short term and at the same time develops and implements market-based instruments in the long term. For the short run strategy, important questions raised include those around economic incentives for seafood processing firms' compliance with environmental standards. More specifically, what is the market-based evidence for revising national regulations on the effluent of the aquatic product processing industry (QCVN 11-MT, 2015) which has been weakly enforced for SMEs? For the long run strategy, total cost, and marginal cost of pollution abatement of the entire industry must be estimated for designing sound policy instruments.

The seafood processing industry in Vietnam is important in creating jobs and income for the economy while being poorly environmentally regulated and creating large negative externalities. This study is the first estimating the shadow prices of pollutants from the seafood processing industry in Vietnam. Using a comprehensive survey of firms in the Mekong River Delta, we apply the distance function approach to track the variability of shadow prices of major pollutants across plants. We then analyze the impacts of firm characteristics, technology, environmental regulations, and quality certification on the marginal abatement cost (MAC) of firms. The estimated MAC and its determinants could be an important input for the establishment and implementation of market-based instruments for industry pollution management in Vietnam.

This paper is organized into five main sections. Section 2 reviews the existing literature on MAC measurement and determinants. Section 3 outlines the methodology employed in this study. Section 4 presents the estimation results of MAC and the determinants of shadow prices of pollutants. Section 5 concludes the paper.

2. LITERATURE REVIEW

Two main approaches have been used to derive a value of a pollutant discharging from a production unit: (1) the direct approach that aims to estimate the social damage of discharging an extra volume of pollutant, and (2) the indirect approach that aims to estimate the shadow price of a pollutant, in the form of the MAC of reducing one unit of the discharge. When production units are subject to environmental regulations, the second approach could be employed i.e., pollutants could be incorporated into efficiency and productivity analysis. When facing pollution control regulations, firms may adopt three strategies: (1) replacing polluting inputs with less polluting ones; (2) adjusting production technology to reduce pollution or (3) investing in abatement technology. If firms do not follow the above three strategies, they must reduce their output to meet the pollution target. The cost of output reduction is the opportunity cost for abating the pollution. A distance function approach (Färe et al. 1993) is often applied to derive this opportunity cost or shadow price of undesirable outputs.

Shadow prices of pollutants could be estimated using parametric or non-parametric efficiency models associated with distance functions (Zhang & Choi, 2014). Parametric models use predefined functional forms which could be expressed as translog or quadratic forms. Translog functions fit with a Shephard distance function (see applications in Coggins & Swinton, 1996; Lee 2005) while quadratic functions stick with a directional distance function and have been used in many recent studies on shadow prices of CO2 (Wei et al., 2013; Wang et al., 2013; Chen 2013). The parameters of these production functions could be estimated using linear programming (Aigner & Chu, 1968) or stochastic frontier analysis. However, because linear programming cannot incorporate random errors and the stochastic method does not fully satisfy several conditions of the distance function, such as monotonicity property, the use of the deterministic parametric estimation is more common (Zhou et al, 2014).

After pioneering work by Färe et al. (1993), many studies have focused on air and water pollution with industrial facilities as decision units in the estimation. In the last decades, several studies have examined sulfur oxide and nitrogen oxide from power plants in the U.S. (Turner, 1994; Coggins & Swinton, 1996; Boyd et al, 2002; Swinton et al, 2004; Lee, 2005, Vardanyan & Noh, 2006; Atkinson & Dorfman, 2005). In the 2010s, as research topics related to climate change gained the spotlight, estimating the shadow price of CO2 emissions as well as other greenhouse gases has attracted much attention, especially in China (Gupta, 2007; Park & Lim, 2009; Lee, 2011; Yuan et al, 2012; Wei et al., 2013; Wang et al., 2013). Most studies have been conducted on industrial establishments in the U.S. and more recently in China.

Regarding water pollutants, shadow prices of biochemical oxygen demand, chemical oxygen demand and total suspended solids were estimated for paper and pulp mills (Färe et al., 1993; Hailu & Veeman, 2000), sugar firms (Murty et al., 2006), paper recycling households (Ha et al, 2006), wastewater treatment plants (Hernández-Sancho et al., 2010), and rural water utilities (Mosheim & Ribaudo 2017).

While shadow prices of pollutants have been widely estimated for industrial establishments in developed countries (e.g. see Zhou et al, 2014 for a review on estimation of shadow prices of undesirable outputs), the literature on developing countries is limited. Industrial production activities in developing countries are often different from those in developed countries with respect to scale of operations, technology, input factors, and factor intensity. For example, firms in developing countries use more labor-intensive technology while firms in industrialized countries use more capital-intensive technology.

The estimation of the MAC of water pollutants has received significant attention in the literature, particularly in developed countries, where research has matured in this area. However, the attention has also extended to developing countries, such as China, Sri Lanka, and India. Studies conducted in these countries, including Gao et al. (2021), Wang, Wang, and Nan (2022), Xie, Shen, and Wei (2017), Xie et al. (2022), Yu et al. (2021), Zhang, Huang, and Qi (2022), Gunawardena et al. (2017), and Singh and Gundimeda (2021), highlight the growing interest in understanding MAC in a developing country context. Some research has been done on estimating water pollutants' MAC as a function of covariates (Singh and Gundimeda, 2021; Xie, Shen, and Wei, 2017; Xie et al., 2022; Zhang, Huang, and Qi, 2022), however very few covariates were used in these studies, probably because of data unavailability.

3. METHODOLOGY

Let's consider a production process that uses a vector of input x to produce good outputs y and bad output b, the relationship between inputs and outputs is reflected in a production possiblity set

$$P(x) = \{(y, b): x \in \mathbb{R}^{+} \; can\; produce\; (y, b) \in \mathbb{R}^{+}\}$$

Given that the output set $P(x)$ is convex, and under the weak disposability of good output, it is possible for firms to reduce good outputs without reducing polluting outputs, but impossible to reduce polluting outputs without reducing the good outputs. In other words, the good and bad outputs are jointly produced and it is costly for firms to reduce bad outputs.

Shadow price and abatement cost

The directional output distance function represents the production technology of good and bad outputs. The directional distance function is defined as follows (Färe et al 2005):

$$\overrightarrow{D_0}(x, y, b; g_y, -g_b) = max\{\beta: (y + \beta g_{y,} b - \beta g_b) \in P(x)\} \qquad (1)$$

where *P*(*x*) is the output set, which includes good outputs *y* and bad outputs *b*, produced from the input vector *x*; $g = (g_{y,} g_b)$ is the directional vector; and β measures the efficiency of the output vector. In Figure 1, for any observation A(*y*,*b*), the firm can increase good output *y* and reduce bad output *b* to get to the frontier at B. The value of *β* is the distance between the observation A and its projection B.

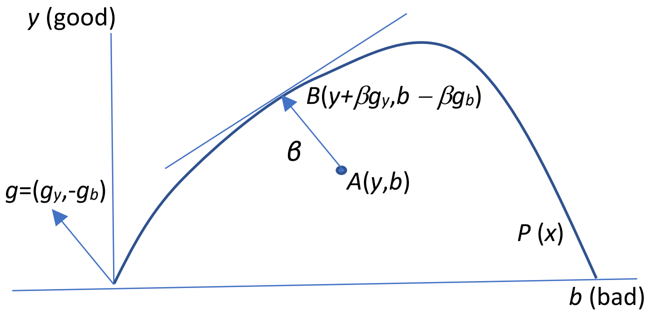

Figure 1: Directional distance function

The shadow price of pollutants can be derived from maximizing the revenue function which accounts for both positive and negative revenues stemming from good and bad outputs:

$$R(x, y, p, q) = max_{y,b}\{yp - bq: \overrightarrow{D_0}(x, y, b; g) \geq 0\} \qquad (2)$$

where *p* and *q* are good and bad output prices.

The estimation of shadow prices of pollutants requires constraints in the optimization problem. It is assumed that good and bad outputs are weakly disposable (Shephard, 1970) i.e., it is possible for bad outputs to reduce if good outputs are reduced in proportion. This implies that firms bear costs to reduce bad outputs in order to comply with environmental regulations.

The shadow price of the pollutant *j* given knowledge of the *m*th output price is

$$q_j = -p_m \left(\frac{\partial \overrightarrow{D_0}(x,y,b;g)/\partial b_j}{\partial \overrightarrow{D_0}(x,y,b;g)/\partial y_m} \right) \qquad (3)$$

The shadow price ratio $-q_j/p_m$ for the observation with coordinate (*y*,*b*) is the slope of the tangent line evaluated on the frontier of *P*(*x*).

Estimation of shadow prices of pollutants

The directional distance function can be estimated using non-parametric or parametric approaches. To estimate the shadow price of pollutants, this study employs parametric specification, in particular the quadratic function using the Stochastic Frontier Analysis (SFA) of (Chung *et al*, 2006; Färe *et al,* 2010).

The directional vector would be set as *g* = (*1*,*−1*) that reflects the simultaneous expansion in processed fish and reduction in pollutants. In the seafood processing industry there are three significant parameters used to assess water pollution: TSS (Total Suspended Solids), COD (Chemical Oxygen Demand), and BOD (Biochemical Oxygen Demand). Among these, TSS can be considered a pollutant itself, as it refers to solid particles suspended in water. On the other hand, COD and BOD are measures that provide information about the biological degradation potential of organic substances (BOD) or both organic and inorganic substances (COD). BOD specifically quantifies the amount of dissolved oxygen consumed by microorganisms during the biological decomposition of organic matter in water. Higher BOD levels suggest the presence of more organic material that can deplete oxygen levels in aquatic environments. COD, on the other hand, is a more comprehensive parameter that encompasses both biodegradable and non-biodegradable organic and inorganic substances. In the context of this study on the MACs of TSS, BOD, and COD, it is important to note that while we refer to them as "three pollutants," readers should understand that BOD and COD are not pollutants themselves but rather indicators of organic and biodegradable substances that contribute to water pollution.

Considering *k* fish processing plants that have four inputs x (capital, labor, fish, and water), one good output y (quantity of processed seafood) and 3 bad outputs (BOD, COD, and TSS), the quadratic form of the directional distance function would be

$$\begin{aligned}\overrightarrow{D_0}(x_k, y_k, b_k; 1, -1) \\ &= \alpha + \sum_{n=1}^{4} \alpha_n x_{nk} + \beta_1 y_k + \sum_{j=1}^{3} \gamma_j b_{jk} + \frac{1}{2} \sum_{n=1}^{4} \sum_{n'=1}^{4} \alpha_{nn'} x_{nk} x_{n'k} + \frac{1}{2} \beta_2 y_k^2 \\ &+ \frac{1}{2} \sum_{j=1}^{3} \sum_{j'=1}^{3} \gamma_{jj'} b_{jk} b_{j'k} + \sum_{n=1}^{4} \delta_n x_{nk} y_k + \frac{1}{2} \sum_{n=1}^{4} \sum_{j=1}^{3} \theta_{nj} x_{nk} b_{jk} + \frac{1}{2} \sum_{j=1}^{3} \mu_j y_k b_{jk}\end{aligned}$$

(4)

We employ the stochastic frontier analysis (Battese and Coelli, 1992; Battese and Coelli, 1995) to estimate parameters in the quadratic function. Because of multicollinearity, some square and interaction terms cannot be included.

For econometric technique, following Färe *et al.* (2005) and Murty (2007), the stochastic specification of the directional distance function could be expressed as

$0 = \overrightarrow{D_0}(x, y, b; 1, -1) + \varepsilon$ (5)

where ε = ν – μ with $\nu \sim N(0, \sigma_v^2)$ and $\mu \sim N(0, \sigma_v^2)$.

The translation property of the directional output distance function implies that

$$\overrightarrow{D_0}(x, y + \alpha, b - \alpha; 1, -1) + \alpha = \overrightarrow{D_0}(x, y, b; 1, -1) \quad (6)$$

By substituting (7) into (6) we have $-\alpha = \overrightarrow{D_0}(x, y + \alpha, b - \alpha; 1, -1) + \nu - \mu$ (7)

Where $\overrightarrow{D_0}(x, y + \alpha, b - \alpha; 1, -1)$ is the quadratic form given by equation (4). As suggested by Färe *et al.* (2005), variation in α in equation (8) can be obtained by choosing α that is specific to each firm. In this study, we could choose α = b, which includes the three water quality indicators BOD, COD, TSS. We will use the maximum likelihood method to estimate the parameters of the quadratic distance function.

Determinants of shadow prices

A regression analysis will be employed to unravel drivers of shadow prices which are different across fish processing plants.

$$q_n^j = \alpha + \beta z_n + \varepsilon_n \quad (8)$$

where q_n^j is the shadow price of pollutant *j* (*j* = BOD, COD, TSS) for *n*-th fish processing plant; z_n is a vector of *n*-th plant characteristics, including pollutant intensity, plant scale, ownership, age, processing technology, and market destination; and ε_n is the random error.

Data sources

Under current regulations, environmental issues are monitored and governed by two organizations, the Ministry of Natural Resource and Environments and the Directorate of the Vietnam Environmental Protection Agency. Production firms are inspected by the local department of natural resource & environment four times a year to assess their compliance with environmental regulations . The data are recorded including the volume of discharge water and contaminant level in wastewater. The data of individual firms are maintained in the Provincial Departments of Natural Resources and Environment (DONRE).

We designed a comprehensive questionnaire with the purpose of collecting essential information pertaining to seafood processing plants situated within the Mekong River Delta region. The questionnaire collects a diverse array of information, including firm characteristics (size, ownership structure, and operational history), inputs (both quantity and prices of raw materials, capital, water usage, and labor), output quantity and price, market destination, quality certification, and technological utilization. We conducted the survey in 7 provinces of the Mekong River Delta of Vietnam, including An Giang, Ben Tre, Ca Mau, Dong Thap, Kien Giang, and Tien Giang.

In order to conduct our survey, we initiated contact with the provincial government to obtain a list of seafood processing firms operating within the province. Subsequently, we made diligent efforts to establish communication with the firm owner or manager from each identified firm, aiming to solicit their participation in the survey. Out of the 300 firms initially contacted, 116 firms responded positively, demonstrating their willingness to contribute to our research endeavor. We collected three years' worth of data, spanning 2016 to 2018, from each participating firm. Achieving this level of data collection required multiple visits and appointments with contacts at the respective firms for conducting interviews. After the initial data collection, we continued to maintain contact with the firms, following up with additional inquiries and requests for clarification.

We obtained data on firm's pollutant intensity and concentration levels from documents the firms submitted to the DONRE, if these were available from the firm. Otherwise, the data on quarterly concentrations of major pollutants were collected for each firm through collaboration with the provincial DONRE. After collecting the necessary data from the participating firms, we established further contact with the DONRE to obtain additional information regarding pollutant concentrations, including BOD, COD, TSS, TN and TP. This collaborative approach ensured that we obtained comprehensive and reliable data on the levels of major pollutants emitted by the seafood processing firms.

4. THE DIRECTIONAL DISTANCE FUNCTION

Data for this study was collected from a sample of 116 firms operating in the seafood processing industry in Vietnam. For each firm, data was collected for up to three consecutive years (2016 to 2018). However, due to temporary shutdowns or other factors, some firms did not have data available for certain years. After accounting for these missing observations, the final dataset consisted of a total of 344 observations. The data was collected from firms located in seven provinces in Vietnam, namely An Giang (23 observations), Ben Tre (17 observations), Ca Mau (138 observations), Dong Thap (20 observations), Kien Giang (71 observations), Long An (3 observations), and Tien Giang (72 observations). This comprehensive dataset spanning multiple provinces provides a robust basis for examining the determinants of the marginal abatement cost (MAC) of water pollutants in the Vietnamese seafood processing industry. After removing observations with missing values there are 341 usable observations.

Table 1 provides a summary of the dataset, presenting key statistics on the firms in the seafood processing industry. On average, a firm in the dataset has been established for 13 years and employs 500 workers, with annual labor costs amounting to 1.4 million US dollars. These firms spend an average of 12.5 million US dollars on raw seafood materials, producing approximately 7,300 tons of output, and earning around 18.7 million US dollars in revenue per year. It is worth noting that the average value of firm assets is nearly 6 billion US dollars, with a significant proportion attributed to land value. While land may not directly contribute to output and revenue, it was not feasible to exclude it from the asset value due to data limitations. Consequently, the coefficient of capital in the analysis reflects the contribution of various asset types, including facilities, machinery, and land, rather than solely facilities and machinery. This, however, does not affect the estimation of the shadow prices of pollutants.

On average, a firm in utilizes approximately 295,000 cubic meters of water per year and discharges a similar volume. The average TSS, BOD and COD values in the discharged water are recorded as 36, 65, and 40 mg/l respectively. Based on the water volume and these concentration values, the estimated BOD and COD loadings are approximately 10.4 and 16.66 tons per year, respectively, while the TSS mass is 10.3 tons per year. It is important to note that the concentrations provided are averages derived from quarterly data over the course of a year. In addition, it is worth mentioning that all firms in the industry employ water filtration systems to treat the inputted water and also treat the released water before discharge. The reported concentrations reflect the levels of pollutants after treatment.

Additionally, it is important to acknowledge that the costs associated with water filtration and treatment were not accounted for in the previously mentioned revenue figures.

Table 1: Summary statistics (N = 341)

	Mean	**SD**	**Min**	**Max**
Firm age	13.16	7.28	2	36
Number of workers	497.73	740.82	18	6500
Revenue (1000 US$)	18,712.87	20,051.43	-11,380.1	107,308
Output quantity (1000 tons)	7.35	6.26	0.05	34.17
Total water use (1000 m3)	295.05	369.94	0.25	1686.35
Capital (mil. USD)	5,980.94	6,283.63	22.41	39,631.86
Labor costs (1000 US$)	1,398.36	2,475.11	24.9	24,043.33
Raw materials (1000 US$)	12,508.9	13,446.03	13.21	67,530.05
BOD concentration (mg/l)	36.06	11.21	14	117.75
BOD discharge (tons)	10.42	14.22	0	77.44
COD concentration (mg/l)	65.31	23.99	17.25	234.5
COD discharge (tons)	16.66	21.43	0.01	130.77
TSS concentration (mg/l)	40.07	17.41	4	186.75
TSS discharge (tons)	10.31	12.98	0.01	64.73
Output price (US$/ton)	3,065.53	2,435.57	21.38	13,069.63
Firm ownership	Household business			18 (5.28%)
	Private enterprise			33 (9.68%)
	Limited liability company			152 (44.57%)
	State-owned joint stock company			30 (8.80%)
	Joint stock company			108 (31.67%)
	Riverside or coastal area	291 (85.34%)	Others	50 (14.66%)
Water treatment	Outsourced	32 (9.38%)	Self treatment	309 (90.62%)
Penalized for non-compliance	No	216 (63.34%)	Yes	125 (36.66%)
Compliance commitment	No	111 (32.55%)	Yes	230 (67.45%)
Raw materials certified	No	229 (67.16%)	Yes	112 (32.84%)
ISO certificate	No	238 (69.79%)	Yes	103 (30.21%)
BRC certificate	No	241 (70.67%)	Yes	100 (29.33%)
Other certificates	No	161 (47.21%)	Yes	180 (52.79%)
Technology	Automated machinery	135 (39.59%)	Manual	206 (60.41%)
Target market	Domestic	112 (32.84%)	Export	229 (67.16%)

The sample of firms in the seafood processing industry exhibits diverse ownership structures, including household businesses (5.3%), private enterprises (9.7%), limited liability companies (44.5%), state-owned joint-stock companies (8.8%), and non-state-owned joint-stock companies (31.67%). This diversity signifies a mixture of ownership types, highlighting the dynamic nature of the industry and the participation of different actors in its operations. All firms perform water treatment, and 9.4% outsource the water treatment to a third party. Approximately 67.5% of the firms surveyed reported having signed a document committing to comply with environmental regulations, while 36.7% of the firms indicated that they had been penalized for surpassing permissible water pollutant concentration levels.

According to the data provided, out of the observed firms in the seafood processing industry, 206 firms rely solely on manual tools for their operations, while 135 firms utilize other types of machinery or automated equipment. This indicates that a significant portion of the sampled firms still heavily rely on manual labor and traditional tools in their processing activities. 67.2% of the firms surveyed have identified their target market as export-oriented.

The data analysis reveals the presence of various certifications among the sampled firms in the seafood processing industry. Specifically, in relation to certified raw seafood materials, out of the total firms observed, 112 firms were found to possess this certification, while 229 firms did not hold it. It is worth noting that the raw materials certification is mainly obtained from local authorities, indicating a focus on ensuring the safety and quality of the input ingredients. Firms having HACCP (Hazard Analysis and Critical Control Points) are also considered having certified raw materials. Moving on to ISO certification, 103 firms were identified as certified, while 238 firms did not possess this specific certification. This certification signifies compliance with international standards in areas such as quality management systems. Furthermore, BRC certification, obtained by 100 firms, indicates compliance with the rigorous standards set by the British Retail Consortium. It emphasizes various aspects of food safety and operational excellence. Lastly, the category of "other certifications" primarily includes HACCP, Global GAP, IFS (International Featured Standards), ASC (Aquaculture Stewardship Council), and BAP (Best Aquaculture Practices). These certifications predominantly focus on ensuring product safety, quality, and sustainability in the seafood processing industry, with 180 firms being certified and 161 firms not holding any of these additional certifications.

Table 2: Estimated directional distance function (N = 341)

	OLS	**SFA**
(Intercept)	-2807	-1425.3
	(2673)	(1.289)
Output quantity (thousand tons)	1207***	1207.3
	(239.9)	(1.791)
Square of output	-10.84	-10.684**
	(10.45)	(4.82)
Capital (mil. USD)	-0.247	-0.253
	(0.197)	(0.166)
Square of capital	0.00001**	0.00001***
	(0.00001)	(0.00001)
Total water use (thousand m3)	-33.39***	-33.454***
	(8.247)	(4.708)
Square of water volume	0.007	0.007*
	(0.004)	(0.004)
Labor cost (1000 US$)	2.26***	2.256***
	(0.347)	(0.282)
Raw materials (1000 US$)	0.844	0.843
	(0.056)	(0.046)
BOD (tons)	156	156.01
	(144)	(1.081)
COD (tons)	102.2	102.2
	(88.67)	(1.133)
TSS (tons)	12.87	12.864
	(136.8)	(1.017)

Control for province and year fixed effects	Yes	Yes

*Note: the dependent variable is revenue (in thousand USD). ***, ** and * indicates significant at 1%, 5% and 10% respectively. Province and year fixed effects are controlled but not presented in this table.*

Table 2 presents the regression results for equation 4 using OLS and SFA. The OLS and SFA estimates are very close, indicating the robustness of the results. Although the data is panel data, several firms provided information for only one year. This, together with high multicollinearity, make it infeasible to employ the full panel data models. To address the nature of panel data, we include province and year dummy variables to control for unobserved heterogeneity.

Using the estimates obtained from Table 2, we calculated the MAC for three water pollutants, namely BOD, COD, and TSS, specifically for seafood processing firms. The average MAC values for BOD, COD, and TSS are estimated to be 463 US$/ton, 303 US$/ton, and 38 US$/ton, respectively (see Table 3). These figures represent the cost incurred from reducing one ton of each respective pollutant in the wastewater generated by seafood processing operations.

The estimated shadow prices of the three water pollutants are lower than those found in the literature for other countries. The shadow price of COD was estimated as 2,800 US$/ton for the leather industry in India (Singh and Gundimeda, 2021), 2,611 US$/ton for industrial firms in China (Zhang et al., 2022), and 1,279 US$/ton for the agricultural sector in China (Tang et al., 2016). The situation is similar for our estimates of BOD and TSS shadow prices. However, it should be noted that shadow prices are industry specific and heavily dependent on output prices, besides many other factors.

Our estimated shadow prices of pollutants are also slightly different from the ”environmental protection fee” stipulated by Decree No. 53/2020/ND-CP of the Vietnamese government. Under this decree, COD emissions are charged at 85 US$/ton (2000 VND/kg) and TSS at 102 US$/ton (2,400 VND/kg). Our estimated shadow price of COD is 3.5 times higher than the fee, while that of TSS is much lower than the charge. The shadow price of COD being higher than the charge suggests that firms may be less incentivized to reduce their COD emissions in response to the charge. This implies that although the charge is effective in raising revenue, it may be less effective in encouraging firms to take action to reduce COD pollution. The reverse is probably true for TSS. The TSS charge may provide a significant incentive for seafood processing firms to reduce their TSS discharge, as their MACs are much lower than the fee.

Table 3: Shadow prices (US$/ton) of BOD, COD and TSS (N = 335)

	Mean	SD	**Median**	**Min**	**Max**
BOD	463.24	333.43	485.15	75.25	1722.29
COD	303.46	218.42	317.81	49.29	1128.23
TSS	38.2	27.49	40	6.2	142.01

Notes: *6 observations were removed for outliers.*

Table 4 presents the MACs of the three water pollutants categorized by firm ownership. The table includes various ownership types such as household businesses, private enterprises, limited liability companies, and privately and state-owned joint stock companies. Analyzing the results across ownership types, we can observe some variations. Household businesses and private enterprises show higher mean and median MAC values for BOD, COD, and TSS than other ownership types. Limited liability companies, on the other hand, exhibit lower mean and median MAC values, indicating potentially lower costs for pollution abatement. State-owned joint stock companies and other joint stock companies fall into the middle range, with moderate mean and median MAC values. These findings suggest that the ownership type of seafood processing firms can influence the costs associated with reducing water pollutants.

Table 4: Marginal abatement cost (US$/ton) of BOD, COD and TSS by firms' ownership.

		BOD		**COD**		**TSS**	
Ownership	N	Mean	Median	Mean	Median	Mean	Median
Household business	18	597.17	584.99	391.19	383.21	49.24	48.24
Private enterprise	33	590.77	554.45	387.00	363.21	48.71	45.72
Limited liability company	152	375.36	345.04	245.89	226.03	30.95	28.45
State-owned joint stock company	24	456.72	524.64	299.19	343.68	37.66	43.26
Joint stock company	108	527.08	506.72	345.28	331.94	43.46	41.78

Table 5 displays the marginal abatement cost (MAC) values in US dollars per ton for BOD, COD, and TSS, categorized by different certifications obtained by the seafood processing firms. Firms with raw materials certification show lower mean and median MAC values for BOD, COD, and TSS than those without certification. This suggests that having a raw materials certification may contribute to lower costs associated with pollutant abatement.

Similarly, firms with ISO certification exhibit lower mean and median MAC values compared to those without certification, indicating potential cost advantages associated with ISO certification. However, firms with BRC certification have higher mean and median MAC values for all pollutants, suggesting that the BRC certification may be associated with higher abatement costs. Finally, firms with other types of certification demonstrate lower mean and median MAC values for all pollutants than those without certification. This indicates that obtaining other types of certifications may potentially lead to cost savings in pollution abatement efforts. The results suggest that the presence of certain certifications can influence the marginal abatement costs of water pollutants in seafood processing firms.

Table 5: Marginal abatement cost (US$/ton) of COD, COD and TSS and certifications

			BOD		**COD**		**TSS**	
Certification		N	Mean	Median	Mean	Median	Mean	Median
Raw materials certification	No	226	396.39	439.08	259.66	287.63	32.69	36.21
	Yes	109	601.85	539.11	394.26	353.16	49.63	44.45
ISO	No	235	432.03	482.07	283.02	315.79	35.62	39.75
	Yes	100	536.58	506.72	351.50	331.94	44.24	41.78
BRC	No	241	392.89	386.97	257.37	253.50	32.40	31.91
	Yes	94	643.62	543.08	421.62	355.76	53.07	44.78
Others	No	158	610.32	546.96	399.81	358.30	50.33	45.10
	Yes	177	331.95	228.91	217.45	149.95	27.37	18.88

We conducted regression analyses to examine the determinants of the shadow prices of the three water pollutants in the seafood processing industry. The results of these regressions are presented in Table 6. In each regression, the dependent variable is the logarithm of the MAC for the respective pollutant. The independent variables included in the regressions are the logarithm of pollutant intensity, the logarithm of total assets value, the logarithm of the number of workers, firm characteristics, water treatment and compliance, certification, and target market.

Firm characteristics include firm age, ownership (with household business as the base category and other categories including private enterprise, limited liability company, state-owned joint stock company, and other joint stock company), and location (whether the firm is located in coastal/riverside areas). For water treatment and compliance, covariates include whether the firm has self-wastewater treatment facilities, whether the firm has been penalized for non-compliance. Certification includes a set of dummy variables including whether the firm has a compliance commitment, whether the firm has raw materials certification (coded as 1 for yes), whether the firm has ISO certification, whether the firm has BRC certification, whether the firm has other certifications, and the target market of the firm (coded as 1 for export and 0 for domestic).

Table 6: Regression of pollutants' shadow prices

	BOD	**COD**	**TSS**
Intercept	5.273 (0.276)	4.878 (0.277)	2.784 (0.281)
log(Pollutant discharge – BOD/COD/TSS)	-0.023 (0.025)	-0.023 (0.026)	-0.048* (0.025)
log(Total assets value)	0.026 (0.025)	0.025 (0.025)	0.034 (0.025)
log(Number of workers)	0.18*** (0.033)	0.179*** (0.033)	0.183*** (0.033)
Firm age	0.009*** (0.003)	0.009*** (0.003)	0.01*** (0.003)
Ownership (base = household business)			
Private enterprise	-0.074 (0.074)	-0.075 (0.074)	-0.081 (0.076)
Limited liability company	-0.253*** (0.073)	-0.252*** (0.072)	-0.263*** (0.075)
State-owned joint stock company	-0.322*** (0.106)	-0.324*** (0.106)	-0.34*** (0.108)
Joint stock company	-0.195** (0.087)	-0.195** (0.087)	-0.207** (0.088)
Located in coastal/riverside areas (1 = Yes)	-0.218*** (0.071)	-0.22*** (0.07)	-0.226*** (0.07)
Self wastewater treatment (1= Yes)	-0.024 (0.067)	-0.023 (0.067)	-0.055 (0.068)
Penalized for non-compliance	0.04 (0.06)	0.04 (0.06)	0.035 (0.059)
Compliance commitment	-0.071 (0.096)	-0.07 (0.096)	-0.066 (0.096)
Raw materials certified (1 = Yes)	0.094 (0.072)	0.094 (0.074)	0.076 (0.072)
ISO certification (1 = Yes)	-0.201*** (0.072)	-0.201*** (0.072)	-0.194*** (0.073)
BRC certification (1 = Yes)	0.259** (0.102)	0.26** (0.103)	0.268*** (0.1)
Other certification (1 = Yes)	-0.262*** (0.069)	-0.263*** (0.069)	-0.277*** (0.07)
Target market (1 = export,0 = domestic)	0.077 (0.074)	0.077 (0.075)	0.066 (0.074)
R squared	0.794	0.793	0.795

N	335	335	335

*Note: the dependent variable is a logarithm of shadow prices of pollutants. Robust standard errors are in parenthesis. ***, ** and * indicate significance at 1%, 5% and 10% respectively. Province and year fixed effects are controlled but not presented in this table.*

For TSS, the MAC decreases with TSS discharge. A one percent increase in TSS load is associated with a decrease of 0.05 percent in the MAC of TSS. As pollution reduction progresses, marginal abatement costs tend to rise steeply, indicating that it becomes more expensive to further reduce pollution beyond a certain point due to technological or infrastructure constraints (Zhang, Huang, and Qi, 2022; Singh and Gundimeda, 2021). However, BOD and COD loads do not affect the corresponding MAC in our results. This is not theoretically expected, but at times found in the literature (Singh and Gundimeda, 2021; Murty and Kumar, 2002; and Murty et al. 2007).

We anticipate that capital-intensive firms would exhibit higher shadow prices due to their advanced technology, making additional pollution reduction costly, while labor-intensive firms are expected to have lower shadow prices. However, capital intensity does not affect the MAC of any pollutants, while firms with more workers tend to have higher MACs. A one percent increase in the workforce results in approximately 0.18 percent decrease in the MACs of BOD, COD and TSS. This is unexpected, but still consistent with some previous evidence (Singh and Gundimeda, 2021).

The expected relationship between the shadow price and the age of a firm is generally negative, as newer firms tend to adopt more advanced and less pollution-intensive technologies (Singh and Gundimeda, 2021; Coggins and Swinton 1996; Gray and Shadbegian 2003; Wei et al. 2013). However, our results indicate a positive relationship between firm age and shadow price. This unexpected finding could be attributed to our control for technology in the model, resulted in firm age serving as a proxy for business experience. Consequently, older firms may exhibit higher efficiency in production or possess stronger bargaining power in the market, leading to higher MACs.

Private enterprises and household businesses are similar with regard to the MACs for all three pollutants. MACs of limited liability companies and joint stock companies have MACs 20 to 30 percent lower, indicating their advantage in achieving pollution reduction at a lower cost or with greater efficiency. Pollution control for firms located in the coastal areas and riversides is also more cost-effective , with MACs lower by 22 percent. In addition, our analysis did not find any significant differences in the MACs of water pollutants between export-oriented firms and those focused on domestic markets.

Our analysis revealed interesting findings regarding the impact of outsourcing water treatment, non-compliance penalties, and compliance commitment on the marginal abatement costs (MACs) of water pollutants in the seafood processing industry. Surprisingly, we found that these factors did not have a significant effect on the MACs of any of the three water pollutants. This suggests that outsourcing the tasks of water treatment, being penalized for non-compliance, or having a compliance commitment do not lead to significant changes in the costs associated with pollution abatement for seafood processing firms. It is worth noting that our results differ from the findings of Gunawardena et al. (2017), who reported that the MAC of BOD was higher for compliant firms. This disparity could be attributed to various factors, including differences in the sample composition, geographic location, or specific industry dynamics.

Our analysis revealed intriguing findings regarding the impact of using certified raw materials and specific certifications on the MACs of water pollutants in the seafood processing industry. We found that using certified raw materials did not result in any significant changes in the MACs of the three pollutants. This implies that the certification of raw materials alone does not contribute to a significant reduction in water pollution abatement costs for seafood processing firms. However, the presence of the BRC certificate had an adverse effect on the MACs of all three pollutants, resulting in an increase of 26-27%. This suggests that firms with BRC certification face additional challenges and higher costs in their efforts to reduce water pollution, making it more difficult for them to be environmentally compliant. In contrast, the possession of ISO certification or other certifications had a positive impact on the MACs of pollutants, reducing them by 20-28%. This indicates that firms with ISO or other certifications are more cost-effective in their pollution abatement efforts, as they have implemented measures that contribute to lower pollution-related costs.

In summary, our analysis reveals that the MACs of water pollutants are influenced by firm characteristics. This highlights the importance of considering the heterogeneity in abatement costs when implementing uniform pollution reduction standards. Our findings suggest that an efficient policy should allocate a higher abatement burden to firms with lower MACs, as this approach would help achieve pollution reduction targets at a lower overall cost.

5. CONCLUSION

This study is motivated by the significant role of the seafood industry in job creation and its substantial discharge of organic matter into the environment, particularly in riverside and seashore areas. The current policy in Vietnam applies a uniform standard and environmental fee for water pollutants. To investigate the marginal abatement costs (MACs) of three water pollutants (BOD, COD, and TSS), we collected data on production activities and pollutant concentration and intensity from seafood processing firms in the Mekong River Delta region of Vietnam. By employing the directional distance function with stochastic frontier analysis (SFA), we estimated the MACs and conducted regression analyses to examine the relationship between MACs and firm characteristics.

Our findings indicate that the MACs of the pollutants in the seafood industry in Vietnam are lower compared to other countries and differ from the environmental fee imposed by the existing regulations in Vietnam. We also observed significant heterogeneity in the MACs, with younger firms, less labor-intensive firms, limited liability companies (LLCs) and joint-stock companies (against household businesses and private enterprises), firms located in seashore or riverside areas, and those with ISO or other certifications exhibiting lower MACs. These findings suggest that these firms are more cost-efficient in reducing water pollutants. Given the considerable heterogeneity in MACs, our results imply that applying a uniform standard or environmental fee for pollutant discharge is inefficient, and a tradable permit system could be a more effective approach.

It is important to acknowledge some limitations of our study, including the data sampling process, as only 116 out of 300 firms responded, and the inability to include all interactions and square terms in the directional distance function due to multicollinearity. Future research should address these limitations and further explore these issues.

6. REFERENCES

Aigner DJ, Chu SF. (1968) On estimating the industry production function. *American Economic Review* 58:826–39.

Atkinson SE, Dorfman JH. (2005) Bayesian measurement of productivity and efficiency in the presence of undesirable outputs: crediting electric utilities for reducing air pollution. *Journal of Econometrics* 126:445–68

Battese, G.E. and T. Coelli (1992), Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India. *Journal of Productivity Analysis*, 3, 153-169.

Battese, G.E. and T. Coelli (1995), A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20, 325-332.

Chen SY (2013) What is the potential impact of a taxation system reform on carbon abatement and industrial growth in China? *Economic System* 37:369–86.

Coggins JS, Swinton JR (1996) The price of pollution: a dual approach to valuing SO2 allowance. *Journal of Environmental Economic & Management* 30:58–72.

Färe R, Grosskopf S, Lovell CA, Yaisawarng S. (1993) Derivation of shadow prices for undesirable outputs: a distance function approach. *Review of Economic Statistics* 75: 374–80.

Färe R, Grosskopf S, Lovell CA, Noh D, Weber WL. (2005) Characteristics of a polluting technology: theory and practice. *Journal of Econometrics* 126:469–92

Gao, T., Xiao, K., Zhang, J., Zhang, X., Wang, X., Liang, S., ... & Huang, X. (2021). Cost-benefit analysis and technical efficiency evaluation of full-scale membrane bioreactors for wastewater treatment using economic approaches. *Journal of Cleaner Production*, *301*, 126984.

Gunawardena, A., Hailu, A., White, B., & Pandit, R. (2017). Estimating marginal abatement costs for industrial water pollution in Colombo. *Environmental Development*, *21*, 26-37.

Ha N, Kant S, Maclaren V. (2008) Shadow prices of environmental outputs and production efficiency of household-level paper recycling units in Vietnam. *Ecological Economics* 65:98–110

Hailu A, Veeman TS. (2000) Environmentally sensitive productivity analysis of the Canadian pulp and paper industry, 1959–1994: an input distance function approach. *Journal of Environmental Economics and Management* 40:251–74.

Hernández-Sancho F, Molinos-Senante M, Sala-Garrido R. (2010) Economic valuation of environmental benefits from wastewater treatment processes: an empirical approach for Spain. *Science Total Environment* 408:953–7.

Kwak, Y. H., & Ingall, L. (2007). Exploring Monte Carlo simulation applications for project management. *Risk Management*, *9*(1), 44-57.

Lee JD, Park JB, Kim TY (2002) Estimation of the shadow prices of pollutants with production/environment inefficiency taken into account: a nonparametric directional distance function approach. *Journal of Environmental Management* 63:365–75.

Mosheim, R. and M. Ribaudo (2017) Costs of Nitrogen Runoff for Rural Water Utilities: A Shadow Cost Approach. Land Economics vol. 93 no. 1 12-39.

Murty MN, Kumar S, Paul M. (2006) Environmental regulation, productive efficiency and cost of pollution abatement: a case study of the sugar industry in India. *Journal of Environmental Management* 79:1–9.

Park H, Lim J. (2009) Valuation of marginal CO2 abatement options for electric power plants in Korea. *Energy Policy* 37:1834–41.

QCVN 11-MT. (2015). National technical regulation on the effluent of aquatic products processing industry. Ministry of Natural Resource and Environment, Hanoi, 2015. Quy chuẩn kỹ thuật quốc gia về nước thải chế biên thủy sản. Bộ Tài Nguyên & Môi Trường, Hà Nội, 2015.

Sala-Garrido, R., Mocholi-Arce, M., Molinos-Senante, M., & Maziotis, A. (2021). Marginal abatement cost of carbon dioxide emissions in the provision of urban drinking water. *Sustainable Production and Consumption*, *25*, 439-449.

Shephard, R.W. (1970). Theory of Cost and Production Functions. Princeton University Press, Princeton.

Vardanyan M, Noh D. (2006) Approximating pollution abatement costs via alternative specifications of a multi-output production technology: a case of the US electric utility industry. *Journal of Environmental Management* 80:177–90

Singh, A., & Gundimeda, H. (2021). Impact of bad outputs and environmental regulation on efficiency of Indian leather firms: a directional distance function approach. *Journal of Environmental Planning and Management*, *64*(8), 1331-1351.

Singh, A., & Gundimeda, H. (2021). Measuring technical efficiency and shadow price of water pollutants for the leather industry in India: A directional distance function approach. *Journal of Regulatory Economics*, *59*, 71-93.

Venugopal, V. and Sasidharan, A. (2021). Seafood industry effluents: Environmental hazards, treatment and resource recovery. *Journal of Environmental Chemical Engineering* 9(2) https://doi.org/10.1016/j.jece.2020.104758

Ministry of Natural Resources and Environment of Vietnam (MONRE) (2021) 2016-2020 National Environmental Assessment Report.

VNGGS (2012). The National Green Growth Strategy for the period 2011-2020 with a vision to 2050. Prime Ministry, No. 1393/QniTTg, Hanoi, 25 September 2012.

Wang K, Wei YM, Zhang X. (2013) Energy and emissions efficiency patterns of Chinese regions: a multi-directional efficiency analysis. *Applied Energy* 104:105–16.

Wang, F., Wang, R., & Nan, X. (2022). Marginal abatement costs of industrial CO2 emissions and their influence factors in China. *Sustainable Production and Consumption*, *30*, 930-945.

Wei, C, Löschel A, Liu B. (2013) An empirical analysis of the CO2 shadow price in Chinese thermal power enterprises. *Energy Economics* 40:22–31

Xie, H., Shen, M., & Wei, C. (2017). Assessing the abatement potential and cost of Chinese industrial water pollutants. *Water Policy*, *19*(5), 936-956.

Xie, H., Wang, X., Shen, M., & Wei, C. (2022). Abatement costs of combatting industrial water pollution: convergence across Chinese provinces. *Environment, Development and Sustainability*, 1-16.

Yu, Q. W., Wu, F. P., Zhang, Z. F., Wan, Z. C., Shen, J. Y., & Zhang, L. N. (2021). Technical inefficiency, abatement cost and substitutability of industrial water pollutants in Jiangsu Province, China. *Journal of Cleaner Production*, *280*, 124260.

Yuan P, Liang W, Cheng S. (2012) The margin abatement costs of CO2 in Chinese industrial sectors. *Energy Proc* 14:1792–7.

Zhang, N., Choi, Y. (2014) A note on the evolution of directional distance function and its development in energy and environmental studies 1997–2013. Renewable and Sustainable Energy Reviews, 33, 50-59.

Zhang, N., Huang, X., & Qi, C. (2022). The effect of environmental regulation on the marginal abatement cost of industrial firms: Evidence from the 11th Five-Year Plan in China. *Energy Economics*, *112*, 106147.

Zhou.P, Zhou, X. and L Fan (2014) On estimating shadow prices of undesirable outputs with efficiency models: A literature review. *Applied Energy* 130: 799–806