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Environmental Efficiency Evaluation in Vietnam Textile and Garment Industry: Super-SBM Model with Undesirable Output Approach

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ABSTRACT

The purpose of the paper is to estimate the environmental efficiency of the Vietnamese textile and garment industry and evaluate the impact of the factors on environmental efficiency. The study uses firm-level panel data from the Vietnam annual enterprise survey data for the 2012–2018 period in the Vietnam textile and garment industry to evaluate the environmental efficiency by using the Super-SBM DEA model with undesirable output and applies the Tobit regression model to measure the impact of the factors on the environmental efficiency. This study evaluates environmental efficiency and assesses the impact of some core factors, including the origin of imported machinery and equipment, the origin of imported materials, the management of industrial zones, and the presence of FDI firms, on environmental efficiency at the firm level. The results indicate that the average score for environmental efficiency is 0.233. Some factors, such as income per employee, machined goods imported from developed countries, industrial zones, firm improvement processes, and the presence of FDI, have a positive impact on a firm's environmental efficiency, whereas materials made in Vietnam have a negative impact.

INTRODUCTION

After 35 years of implementing an economic renovation policy (known as *Doi Moi),* launched in 1986, Vietnam has made notable economic achievements. Vietnam's GDP grew from $6.472 billion in 1990 to $343 billion in 2020. Vietnam's economic structure is shifting toward modernization, with agriculture contributing less and industrial and service production contributing more. Exports have frequently experienced rapid growth, especially in manufactured goods such as textile and garment products, food products, footwear, electrical machinery, and equipment. However, with the high growth of Vietnam's industry, the country is facing high energy consumption and high carbon dioxide emissions, which have resulted in environmental pollution and climate change. The textile and garment industry plays an important role in Vietnam's economic growth, contributing 10% of industrial production value, supporting nearly 3 million jobs in Vietnam, and ranking third worldwide in exports with a value of about $36 billion in 2020. However, for various textile manufacturing processes, this industry relies on the use of a large amount of water, energy, and toxic chemicals, resulting in a variety of waste streams, including gaseous, liquid, and solid forms. Vietnam has about 180 firms operating in the field of dyeing and finishing textiles: 70 floral print lines, 200 dyeing lines, 750 dyeing machines, and about 100 yarn dyeing machines. However, the technology level in the dyeing industry is about 15–20 years lower in comparison with other countries in the area. In Vietnam, the amount of chemicals used in textile and dyeing firms ranges between 500 and 2,000 kg per ton of product. Therefore, the textile and garment industry has become one of the most polluted industries in Vietnam. To sustain economic growth in conditions of environmental protection for the industry, evaluation of the environmental pollution effects, analysis of the factors that influence environmental efficiency, and provision of the scientific basis for environmental efficiency improvement are required.

Under consideration for environmental efficiency measurement, there are two main methods used in previous literature: parametric Stochastic Frontier Analysis (SFA) and non-parametric Data Envelopment Analysis (DEA). The DEA method, developed by Charnes et al. (1978), is better suited for efficiency evaluation because it does not require prior assumptions about the production function and can handle multiple inputs and outputs at the same time (Cooper et al. 2007, Asmild et al. 2004, Pulina et al. 2010). Standard DEA models provide a radial input-oriented or output-oriented efficiency measurement. When some undesirable inputs or outputs (e.g., pollutants, emissions, or wastes) occur in the model, the undesirable outputs or undesirable inputs should be adjusted to improve efficiency. As a result, evaluating efficiency becomes a difficult problem when environmental pollutants are present in the model, especially when these pollutants do not have the same proportions of increase or decrease with inputs or outputs. Based on DEA models, there are a number of methods being developed to handle undesirable outputs, such as the BCC (Banker, Charnes, and Cooper) model (Fare et al. 1989, Seiford & Zhu 2002), the SBM (slack-based measure) (Chu et al. 2018, Tone 2002, Zhang & Kim 2014), the additive DEA model (Charnes et al. 1985) and the super-SBM efficiency model (Tone 2004, Li et al. 2013). Fare et al. (1989) made two modifications to the standard Farrell approach, which allows the expansion of good outputs and the contraction of bad outputs using a single scalar to make the measure nonlinear. However, this study does not consider the positive effects of decreasing the environmental pollution. Hailu & Veeman (2001) applied non-parametric analysis as extended by the Chavas-Cox approach to calculate environmental efficiency. They treat undesirable outputs as input variables and handle the issue to decrease the undesirable outputs and maximize desirable outputs. Based on the standard linear BCC DEA model of Banker et al. (1984), Seiford & Zhu (2002) evaluated the environmental efficiency by converting the undesirable output's negative number into a positive input through vector transformation. Fare et al. (2003) proposed an output-oriented distance function to estimate energy efficiency by using output and input forms, but the problem of the slack variables was not explained. Tone (2002) proposed a non-oriented efficiency evaluation model called the Slack-Based Model (SBM). Tone (2002) can betel deal with the slack variables, but this study does not consider the undesirable outputs. Tone (2004) and Li et al. (2013) then propose the super-SBM model to evaluate environmental efficiency. The super-SBM has an advantage due to its higher discriminating ability when dealing with slack variables and undesirable outputs. These studies mainly focus on measuring environmental efficiency, and some of them initially evaluate factors affecting environmental efficiency at the macro level (Li et al. 2013, Honma 2015, Grigoroudis & Petridis 2018). While many core factors at the firm level, including the origin of imported machinery and equipment, the origin of imported materials, the management of industrial zones, and the presence of FDI firms, are not discussed.

As mentioned above, the textile and garment industries are one of the most polluted industries in Vietnam. Support policies for exporting textile and garment products may increase exports and economic growth while increasing pollution in the industry if no other environmental policies are in place. Previous studies have only focused on factors that affect pure efficiency, leaving out environmental efficiency, which is critical for the long-term development of the Vietnam textile and garment industry. To investigate the impact of these factors on environmental efficiency at the firm level, in this paper, the Super-SBM model with undesirable outputs is used to calculate environmental efficiency in Vietnam's textile and garment industry, and then the Tobit regression model is applied to evaluate the factors affecting environmental efficiency based on Vietnam-specific conditions. To examine whether the efficiency scores vary among different groups (firm scales, regions), the Kruskal-Wallis rank test is used. This paper is believed to provide support for the government's issuing appropriate policies relating to environmental protection in the sustainable development of Vietnam's textile and garment industry.

MATERIALS AND METHODS

Super-SBM Model for Efficiency Evaluation

Each firm in the textile and garment industry is called a decision-making unit (*DMU*). Suppose having *n* decision-making units (*n DMUs*). There are three factors in each unit: input, desired outputs, and undesirable outputs (environmental pollution, CO_2, ...), defined by three vectors $x \in R^m$, $y^g \in R^{S1}$, $y^b \in R^{S2}$, respectively. The matrices X, Y^g, and Y^b are defined as follows:

$$X = [x_1, x_2, \dots, x_n] \in R^{m \times n}$$

$$Y^g = [y_1^g, y_2^g, \dots, y_n^g] \in R^{s_1 \times n},$$

$$Y^b = [y_1^b, y_2^b, \dots, y_n^b] \in R^{s_2 \times n},$$

It is assumed that $X > 0$, $Y^g > 0$, and $Y^b > 0$. According to Banker et al. (1984), the production possibility set is defined as:

$P = \{(x, y^g, y^b) \mid x \geq X\lambda, y^g \leq Y^g\lambda, y^b \geq Y^b\lambda, \lambda \geq 0, e\lambda=1\}$,

Where, $\lambda \in R^n$ and *e* is a row vector with all elements equal to *1*.

The SBM model with undesired outputs to evaluate the *DMU* (x_0, y_0^g, y_0^b) is as follows (Tone 2004):

[SBM -Undesirable]

$$\rho^* = \min_{s^-, s^b, s^g, \lambda} \left\{ \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s_1 + s_2}\left(\sum_{r=1}^{s_1}\frac{s_i^g}{y_{r0}^g} + \sum_{r=1}^{s_2}\frac{s_r^b}{y_{r0}^b}\right)} \right\} \quad \dots(1)$$

Subject to. $x_0 = X\lambda + s^-$ ... (2)

$$y_0^g = Y^g\lambda - s^g \quad ...(3)$$

$$y_0^b = Y^b\lambda + s^g \quad ...(4)$$

$$s^- \geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0, e\lambda=1 \quad ...(5)$$

Where s^- and s^b correspond to excesses in inputs and undesirable outputs, respectively, while s^g indicates shortages in desirable outputs, λ is the intensity vector. The target function value of $\rho*$ is the environmental efficiency value (EE*) of DMU (x_0, y_0^g, y_0^b).

The equation (1) - (5) is a nonlinear programming problem with the nonlinear objective function in s^-, s^g, s^b and with the constraints of the linear presented in (2) - (5). The minimum value of the objective value function satisfies $0< \varrho* <1$. DMU (x_0, y_0^g, y_0^b) is SBM efficiency with undesirable outputs if and only if $\varrho* = 1$, that is, $s^-=0$, $s^g=0$, $s^b= 0$. If $\varrho* <1$, that means the DMU is inefficient.

Problem (1) - (5) is a nonlinear programming problem. By using the Charnes-Cooper transform (Charnes 1952), it can be transformed into a linear programming problem. An equivalent linear programming problem in t,ν, s^-, s^g and s^b is constructed as follows:

$$\text{[LP]}\ \theta* = \min_{S^-,S^g,S^b,t,\nu} \left\{ t - \frac{1}{m}\sum_{i=1}^{m}\frac{S_i^-}{x_{i0}} \right\} \quad ...(6)$$

Subject to $$1 = t + \frac{1}{s_1+s_2}\left[\sum_{r=1}^{s_1}\frac{S_r^g}{y_{r_0}^g} + \sum_{r=1}^{s_2}\frac{S_r^b}{y_{r_0}^b}\right] \quad ...(7)$$

$$x_0 t = X\nu + S^- \quad ...(8)$$

$$y_0^g t = Y^g\nu - S^g \quad ...(9)$$

$$y_0^b t = Y^b\nu + S^g \quad ...(10)$$

$$S^- \geq 0, S^g \geq 0, S^b \geq 0, \nu \geq 0, t > 0 \quad ...(11)$$

As shown by Cooper et al. (2007), since $(t*,\nu*, s^{-*}, s^{g*}, s^{b*})$ is the optimal solution of the equation (6)-(11) the optimal solution of [SBM-Undesirable] as defined by

$$\rho*=\theta*, \lambda*=\nu*/t,$$

$$s^{-*} = S^{-*}/t^*,\ s^{g*} = S^{g*}/t^*,\ s^{b*} = S^{b*}/t^*$$

Kruskal-Wallis Rank Test to Examine the Difference of the Environmental Scores Among Groups

To test this stability hypothesis, the study uses the Kruskal-Wallis non-parametric ANOVA test (Brockett & Levine 1984). There are simultaneously N "overall" (firms) under consideration and the original hypothesis (Ho) is that all N totals have the same score distribution. Firstly, ranking the set of $N.k$ points in ascending order (equal positions are also taken in the middle-rank position) and the symbol Rj is the sum of the rank positions corresponding to the DMU (bank). Then, the Kruskal-Wallis test is calculated as follows:

$$H = \frac{12}{N\cdot k\cdot(N\cdot k+1)}\cdot\left(\frac{R_1^2}{k}+\frac{R_2^2}{k}+...+\frac{R_N^2}{k}\right) - 3\cdot(N\cdot k+1) \quad ...(12)$$

H ~ χ^2_{N-1} with N-*1* degrees of freedom. If χ^2_{N-1} larger than χ^2_{N-1} at the desired significance level, the null hypothesis of the distribution of efficiency ratings similar to all DMUs is rejected at given the significance level.

Tobit Regression Model for Evaluating Factors Affecting the Environmental Efficiency

After estimating environmental efficiency from the Super-SBM model, the study explores factors affecting on environmental efficiency, especially factors restricting efficiency. Traditional OLS methods may have the problem of asymmetry or inconsistency when dealing with censored or truncated data as environmental efficiency. To solve problems with limited dependent variables and investigates the determinants of truncated variables such as environmental efficiency, the study applies the Tobit model proposed by Tobin (1958). The standard model is as follows:

$$y*_i = \beta X_i + \mu_i;\ \mu_i \sim N(0, \sigma^2),\ i=1, 2, ..., n, \quad ...(13)$$

Where n is the number of observations, i is the i^{th} DMU, $y*_i$ is a latent variable, X_i is a $Kx1$ matrix of independent variables, μ_i is an independently-distributed error, which is assumed N (0, σ^2) distribution. β is a vector of unknown coefficients. The limited sample value y_i is:

$$y_i = \begin{cases} y_i^*, & y_i^* > 0 \\ 0, & y_i^* \leq 0 \end{cases} \quad ...(14)$$

DATA AND ESTIMATED RESULTS

Data

The data used in the study are collected from two surveys: the Annual Enterprise Survey and the technology survey conducted by the General Statistics Office (GSO) which was obtained from 2012 to 2018 (The most updated data in the present). These two sets of data are grouped together into a set of survey data which included both firm technology activities and general information about firm characteristics, financial accounts, and energy consumption. The firms which don't report energy consumption, total wages, assets, number of workers, and revenue are not positive or in the case of incomplete replies are also dropped. Variables in monetary values are calculated in VND millions and adjusted for various years using annual inflation rates. After removing the firms in other industries and generating balanced datasets of Vietnam's textile and garment industry, the database includes 324 firms in Vietnam's textile and garment sector (2.268 observations in total over the 2012-2018 period).

Environmental Efficiency in Vietnam Textile and Garment Industry

Inputs and outputs used for the Super-SBM model: Capital and labor are the most important production inputs in terms of input variables. In most studies, real capital stock (K), as measured by total fixed assets - depreciation (Mil. VND), is a desirable indicator for capital investment. The number of firm employees at the end of each year is used as an indicator of labor input (L) (Person). Each firm must use one or more sources of energy (such as coal, oil, gasoline, ...) to meet production needs. Each category of used energy has different technical parameters, making it difficult to assess a firm's total energy consumption. To solve the above problem, the unit "Ton Oil Equivalent - TOE (Ton Oil Conversion)" was counted as the common standard for various energy category evaluations. The TOE unit was used in the research referred to in document No. 3505/BCT-KHCN, April 19, 2011. The consumption quantity of the four major energy sources of firms is converted into a unified unit of TOE, including coal, oil, natural gas, and gasoline. The measurement unit of energy input is set as "tons of standard TOE". In the paper, TOE is used as an energy input variable for the Super-SBM model.

For the output indicators, value-added (VA), desirable output, is defined as the value of gross output subtract from intermediate inputs. Based on the factor income approach, in this study, value-added is determined by the incomes of labor and capital separately in which, capital income is defined as the sum of firm depreciation and total profit. CO_2 emission (*Emis*) is considered an undesirable output. In fact, there is less detailed data on CO_2 emissions for each firm in Vietnam. Therefore, the calculation of CO_2 emissions from firm energy consumption is based on the IPCC reference approach (IPCC 2006) and Chen et al. (2010). Firm CO_2 emission from energy consumption (coal, oil, natural gas, gasoline) is constructed as follows:

$$CO_{2t} = Emis_t = \sum_{i=1}^{4} Emis_{i,t} = \sum_{i=1}^{4} Eng_{i,t} * NCV_i * CEF_i * COF_i * \left(\frac{44}{12}\right) \quad \ldots(15)$$

Where, $CO_{2t} = Emis_t$ = flow of carbon dioxide with the unit of tons, NCV_i (TJ/Gg) = net calorific value provided by 2006 National Greenhouse Gas Inventories in IPCC (2006), CEF_i (ton/GJ) = carbon oxidization factor provided by IPCC (2006), COF_i is the carbon oxidization factor set to be 1 in this study. (44/12) is the molecular weight ratio of CO_2 to carbon. Therefore, based on equation (15), the calculated

Table 1: Descriptive statistics of some input and output variables from 2012 to 2018.

Variables	Input variables			Output variables	
	K (capital) (Mil. VND)	L (labor) (Persons)	TOE (Ton Oil Equivalent) (tons)	VA (Value -added) (Mil. VND)	CO_2 (CO_2 emissions) (tons)
	x_1	x_2	x_3	y^g	y^b
Mean	102496.1	844.827	2467.79	15871.1	5318.004
Std.Dev.	689659.5	1348.126	34672.92	40385.24	67600.43
Maximum	2.18e+07	10656	1061269	782315.6	2.40e+09
Minimum	93.278	4	0.0102	55.32	32.672
Skewness	26.44	2.943	26.605	10.076	28.444

Source: the author estimates from annual surveys of GSO.

Table 2: Pearson correlation of input and output variables.

Correlation	K	L	TOE	VA	CO_2
K	1.0000				
L	0.1988***	1.0000			
TOE	0.8221***	0.1121***	1.0000		
VA	0.7638***	0.6360***	0.7556***	1.0000	
CO_2	0.9110***	0.1211***	0.9519***	0.7391***	1.0000

*** p<0.01. Source: the author estimates from annual surveys of GSO.

CO_2 emission for coal is 2.259 (ton CO_2/ton coal), for oil 3.153 (ton CO_2/ton oil), for natural gas 2.983 (ton CO_2/1000 m^3 natural gas) and for gasoline 3.069 (ton CO_2/1000 liter).

Table 1 reports summary statistics for Vietnam's Textile and garment industry in the period 2012-2018. In general, the value of variables increases over the years. Especially, the growth rates of value-added are higher than those of capital and labor variables (an increase of 159% in 7 years). However, TOE consumption and CO_2 emission are at a very high growth rate (334% and 298% in 7 years, respectively).

Table 2 shows the correlation between input and output variables. The Pearson coefficient results show that there is a positive correlation between inputs and outputs. There is a high correlation between energy input TOE and desirable outputs (VA), and undesirable outputs (CO_2), reaching 0,7556, and 0.9519, respectively. Therefore, the measurement of efficiency using the Super-SBM model is quite reliable in the sample of Vietnam textile and garment industry

Evaluating environment efficiency of textile and garment firms: The efficiency result calculated from the Super-SBM model is used as independent variables to measure the impact of factors on environmental efficiency by using the Tobit regression model. Table 3 provides a summary statistics of environmental efficiency in Vietnam's textile and garment sector.

The estimation results show a slight decrease in average efficiency over time, with a value of 0.233 on average. In this case, FDI firms' environmental efficiency is 27.9%. The results are lower than the findings of Duong (2016) in Vietnam's textile industry that the technology efficiency without undesirable outputs estimated by Stochastic Frontier Analysis (SFA) is 63.4% for export FDI firms and 47.4% for non-export FDI firms from 2009 to 2013. The results are also lower than the environmental efficiencies estimated by Hongqi et al. (2013) in China's manufacturing industry from 2002 to 2009, with an efficiency score of 0.298. In recent years, although Vietnam has issued some regulations relating to restructuring industrial, protecting the environment, and decreasing the emissions, such as Vietnam's National Energy Development Strategy, the Revised National Power Development Plan (PDP) for 2011-2020, the Law on Environmental Protection, and the National Action Programme on Reduction of GHG Emissions, its enforcement capacity is still weak. Therefore, environmental efficiency has not improved. Being one of the leading export industries with a high growth rate, the entrants of much more textile and garment firms can tend toward higher levels of TOE consumption and CO_2 emission.

Table 3: Environmental efficiency of Vietnam's textile and garment sector.

Variables	2012-2018	2012	2014	2016	2018
Environmental Efficiency (EE)					
Mean	0.233	0.346	0.283	0.230	0.215
Std.Dev.	0.258	0.326	0.205	0.267	0.258
Skewness	1.694	0.972	1.757	1.427	1.740
Observations	2,268	324	324	324	324
Environmental Efficiency (EE) by scales					
Micro and small-sized firms	0.170	0.302	0.259	0.139	0.136
Medium-sized firms	0.121	0.264	0.175	0.059	0.104
Large-sized firms	0.255	0.384	0.313	0.298	0.271
Environmental Efficiency (EE) by ownership					
FDI firms	0.279	0.385	0.323	0.294	0.269
Domestic firms	0.189	0.308	0.242	0.166	0.163

Source: the author estimates from annual surveys of GSO.

Table 4: Environmental efficiency by the origin of imported technology.

Type of firms	EE	CO_2 (Ton)	TOE (Ton)	CO_2/TOE
Firms with main technology imported from developed countries	0.252	6030.853	2938.23	2.05
Firms with main technology imported from developing countries	0.189	1736.189	717.27	2.42
Total sample	0.233	5318.004	2467.79	2.15

Source: the author calculates from annual surveys of GSO.

In general, average environmental efficiency for all scales decreases dramatically over the same time period, particularly for micro and small-sized businesses in which, the efficiency of large-sized firms is always higher than the industry's average level (25.5%). Larger firms are both energy and emission-intensive compared to medium-sized firms. The result is similar to the analysis by Lee & Yu (2019), and Sabtosh & Deepanjali (2019). Large-sized firms with more sophisticated technology can organize production activities more rationally to decrease CO_2 emissions and gain higher environmental efficiency.

Table 4 shows environmental efficiency by the origin of imported technology. Of the total firms under consideration, firms with main technology imported from developed countries accounted for 58.3% (The ratio of FDI firms is over 77%) and gain environmental efficiency much larger by 133% than the others.

Equipment imported from developed countries with a larger scale has used a larger number of TOE and emitted much more CO_2 than equipment imported from developing countries. However, the level of CO_2 emission per TOE unit (2.05) of the firms with a main machine imported from developed countries is lower than those imported from developing countries (2.42), machines imported from developed countries tend to be more environmental efficiency due to better environmental standards and regulations.

Evaluating the Impact of Factors on Textile and Garment Firms' Environmental Efficiency

The Suggestion of Experimental Model Based on the Tobit Regression Model

The theoretical model mentioned above (model 13) is expressed in the following econometric model:

$$EE^*_{it} = \beta_1 * lnKL_{it} + \beta_2 * lnLC_{it} + \beta_3 * lnTrade_{it} + \beta_4 * Machine\_deped_{it} + \beta_5 * Mater\_deping_{it} + \beta_6 * Mater\_VN_{it} + \beta_7 * FDI_{it} + \beta_8 * Improve_{it} + \beta_9 * Industry\_zone_{it} + \beta_{10} * North_i + \beta_{11} * South_{it} + i.Scale_{it} + i.Year + \mu_i \quad \ldots(16)$$

Dependent Variables:

EE^*_{it}: Environmental Efficiency of firm i in the year t, which is estimated from Super-SBM model with undesirable outputs.

Independent Variables:

$lnKL_{it}$: The log of capital intensity, measured by capital stock per employee of the i^{th} firm in the year t. An increase in capital intensity is assumed to increase the labor productivity since more capital per employee is available.

$lnLC_{it}$: The log of human capital, measured by total wages and training costs per employee of the i^{th} firm in the year t. An increase in human capital increases production scale and increases the capability of firms' entering the industry or stay in the industry.

$lnTrading_i$: The log of trade openness, trade openness is measured by the total of exports and imports value of the i^{th} firm. Trade openness reflects the engagement of the i^{th} firm in the global trading system in the year t. The net effect of high trade intensity in the world can tend to generate a positive effect on emissions from developing countries as found by Managi et al. (2009).

$Machine\_deped_{it}$: Dummy variable having a value of 1 if the most important machine of the i^{th} firm i, in the year t is imported from developed countries and has a value of 0 if otherwise. Due to better environmental standards and regulations, machines imported from developed countries tend to be more environmental efficiency. This can reduce pollution in developing countries (Perkins & Neumayer 2009). Therefore, an increase in *machine_deped* is expected to reduce undesirable outputs and improve the firm's environmental efficiency.

$Mater\_deping_{it}$: Dummy variable having a value of 1 if the most important materials of the i^{th} firm, in the year t, are imported from developing countries and having a value of 0 if otherwise. $Mater\_VN_{it}$: Dummy variable having a value of 1 if the most important materials of the firm i, in the year t, are produced in Vietnam and having a value of 0 if otherwise. Using materials from developing countries with a higher level of emission may affect negatively on environmental efficiency (Perkins & Neumayer 2009).

FDI_{it}: Dummy variable having a value of 1 if the i^{th} firm, in the year t, is a foreign-owned firm, having a value of 0 if otherwise. Some research finds that the presence of FDI firms that bring new and advanced technologies into developing countries can improve environmental efficiency while some other studies have suggested that FDI firms can produce higher levels of pollution in developing countries.

$Improve_{it}$: Dummy variable having a value of 1 if the firm i, in the year t, implements activities for manufacturing process improvement, having a value of 0 if otherwise.

$Industry\_zone_{it}$: Dummy variable having a value of 1 if the firm i, in the year t, is in an industrial zone, having a value of 0 if otherwise.

$North_i$: Dummy variable having a value of 1 if the firm i, in the year t, is in the North of Vietnam, having a value of 0 if otherwise.

$South_i$: Dummy variable having a value of 1 if the firm i, in the year t, is in the South of Vietnam, having a value of 0 if otherwise.

Scale$_{it}$: Scale represents for firm's size. The scale has a value of 1 if firm *i*, in the year *t*, is a micro-sized enterprise (less than 10 people employed), having a value of 2 if firm *i* is a small-sized enterprise (less than 100 persons employed), having a value of 3 if the firm *i* is a medium-sized enterprise (less than 200 people employed), having a value of 4 if the firm *i* is large – sized enterprise (200 or more person employed). According to Klepper (2002), larger entrants have higher survival rates. As such, the firms generate higher profits, allocate more resources to research and development, and grow faster.

Table 5 shows the estimation results of influence factors on environmental efficiency by using the Tobit regression model. Evaluating the impact of variables characterized by firms can show that the *lnLC* variable is positive. When income per employee increases by an average of 1%, the environmental efficiency of the firms increases by 0.0304%. Raising employee incomes is an important factor in improving the quality of labor and improving the productivity of the labor force as well as the firm's environmental efficiency. The estimated coefficient of ln*KL* (capital intensity) is negative and statistically significant. This indicates that firms' capital intensity is inefficient. An increase of capital intensity at 1% will cause a decrease of 0.0559% in the enterprises' environmental efficiency. The capital-intensity is always expected to have a positive effect on environmental efficiency, but the negative sign of this variable indicates that capital intensity has not reached the expected results. The cause behind it may be that although the level of capital per worker increased but the capital intensity does not increase accordingly. Combined with an evaluation of the origin of imported machines, it appears that high-tech equipment imported may not be fully exploited. The cause of this phenomenon is that the management level has not fully responded to modern technology or equipment is not synchronous. *Ln_trade* variable is not statistically significant in the model. Trade openness has no significant influence on environmental efficiency.

The estimated coefficient of *Machine_deped* is positive and statistically significant. That means more machines imported from developed countries will increase the efficiency level of this sector. The result is similar to the findings of Perkins & Neumayer (2009), Li et al. (2013). Machine imported from developed countries tends to be more environmental efficiency due to better environmental standards and regulations. Therefore, using technology imported from developed countries can reduce undesirable outputs and improve a firm's environmental efficiency compared to technology imported from developing countries. This level of CO_2 emission per TOE unit (2.05) is lower than machines imported from developing countries (2.42). In fact, the Vietnam government issues many related preferential policies of environmental protection in order to reduce CO_2 emissions from the firm's production process.

From the results estimated in Table 4., the coefficient of *Mater_deping* is negative but not statistically significant, while the coefficient of *Mater_VN* is also negative but statistically significant at 1%. Using materials from developing countries with a higher level of emission may affect negatively environmental efficiency. Therefore, firms' consciousness of environmental protection needs to be improved, especially in the process of importing equipment and materials.

The sign of the FDI variable is positive and statistically significant. The presence of FDI firms with updated technology can bring benefits to this sector, such as a decrease in CO_2 emission, and stimulating competition

Table 5: The estimation results of the Tobit regression model (Model 15).

Dependent variable: Environmental Efficiency			
VARIABLES	Tobit model	VARIABLES	Tobit model
lnKL	-0.0559***	2. Scale	-0.337***
	(0.00747)		(0.0346)
lnLC	0.0304***	3. Scale	-0.357***
	(0.00750)		(0.0427)
ln_trade	-9.24e-05	4. Scale	-0.297***
	(0.00168)		(0.0468)
Machine_deped	0.0208*	13.year	-0.190***
	(0.0120)		(0.0140)
Mater_deping	-0.00254	14. year	-0.0704***
	(0.0155)		(0.0142)
Mater_VN	-0.0401***	15. year	-0.187***
	(0.0150)		(0.0143)
FDI	0.0575**	16. year	-0.125***
	(0.0232)		(0.0164)
Improve	0.0251**	17. year	-0.0331
	(0.00990)		(0.0214)
Industry_zone	0.0350**	18. year	-0.136***
	(0.0142)		(0.0217)
North	-0.0137	Constant	0.981***
	(0.0386)		(0.0688)
South	-0.0233	sigma_u	0.167***
	(0.0406)		(0.00880)
Constant	0.981***	sigma_e	0.177***
	(0.0688)		(0.00300)
Observations	2,268	rho	0.472

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1
Source: the author estimates from annual surveys of GSO.

within the industry. This high competitiveness will force domestic firms to either apply updated technology, and new management method or employ the existing resources more efficiently, which increase firms' environmental efficiency in this industry. The result is similar to the findings by Marques & Caetano (2020), and Demena & Afesorgbor (2020) which show that FDI significantly reduces environmental emissions and improves energy usage efficiency.

The relationship between firm process improvement and environmental efficiency is a positive correlation, which means firm regulation and process renovation can increase efficiency. The Vietnam government has issued many regulations and policies to promote environmental protection technology innovation. These bring more advantages to the firm's process improvement to save the cost of materials and reduce TOE consumptions. Firm environmental efficiency, therefore, is improved.

With more than 325 industrial zones in Vietnam, the industrial zone's influence on environmental efficiency (*Industry_zone*) is positive and statistically significant for the whole country. By 2013, 173 industrial zones had been established, with an average of 90 firms in each zone, the Vietnam government passed basic environmental legislation but regulation and enforcement capacity for implementation was weak. The fast-paced economic development in the industrial zone depended on the high consumption of natural gas, oil, and especially coal, resulting in a rapid increase in CO_2 emissions. As a result, approximately 70% of firms in industrial zones have a high level of CO_2 emissions. Since 2013, the United National Industrial Development Organization (UNIDO) and Vietnam Ministry of Planning and Investment, with support from many international organizations such as Global Environmental Facility (GEF), The U.S. Agency for International Development (USAID), Vietnam tends to implement an eco-industrial park for sustainable industrial zones in Vietnam with many projects such as increasing the transfer, development, and innovation of clean and low-carbon technologies, improving production process for the minimization of CO_2 emission, managing the chemicals as well as raised firm awareness on making optimum use of materials, minimizing environmental pollution. Therefore, the textile and garment firms located in industrial zones can improve environmental efficiency more than other firms.

The region variables (*North, South*) have no significant influence on environmental efficiency. The government should focus on regulations to promote environmental protection and develop a sustainable economy oriented by regions.

Compared with micro-scale firms, the others with a larger scale of production tend to impact more negatively on environmental efficiency. In which, large-scale firms tend to be more efficient than small-scale and medium-scale firms. Large-scale firms applying advanced technology and developing actionable solutions to effectively reduce CO_2 emissions and improve firms' environmental efficiency.

Remarkably, the coefficients of time control variables are all taking negative signs with statistical significance (except for the years of 2017). The government policies to control CO_2 emissions from the textile and garment industry are still weak. As a result, they have no significant influence on environmental efficiency.

Kruskal-Wallis Rank Test to Examine the Differences of Environmental Efficiency Among Sizes and Regions

Table 6 shows the results of the Kruskal-Wallis rank test by size. From the above analysis, it can be seen that the environmental efficiency was different among sizes: Micro-sized firms (n=68); Small-sized firms (n=576); Medium-sized firms (n=224); Large-sized firms (n=1380). The Kruskal-Wallis non-parametric test is used to verify the results of this empirical analysis.

Kruskal-Wallis H test shows that there was a statistically significant difference in environmental efficiency between four scale groups, $\chi_3^2 = 205.685$, Pvalue = 0.0001, allowing rejecting the H_0 hypothesis about the distribution of the same environmental efficiency ranking of four scale groups. Similarly, there was a statistically significant difference in environmental efficiency between the three regions, $\chi_2^2 = 14.921$, Pvalue = 0.0006.

Sensitivity Analysis

Sensitivity analysis is a very important aspect of the super-SBM DEA model to evaluate the robustness of the results. Since super-SBM DEA results can depend on user input and output sets and the results can be changed by any error in the dataset. Sensitivity analysis is examined to see how environmental efficiency through the super-SBM DEA model changes when using different input and output options.

The original model used the super-SBM DEA model, where three inputs and two outputs were selected and called

Table 6: The results of the Kruskal-Wallis rank test by sizes.

Scale of firms	Observation 2012-2018	Rank sum 2012-2018
Micro-sized firms	68	88354
Small-sized firms	576	504300.50
Medium-sized firms	244	211143.50
Large-sized firms	1,380	1.77e+06

Source: the author estimates from annual surveys of GSO.

Table 7: Environmental efficiency value analysis of different indicator combinations.

Overall efficiency	Model M_0	Model M_1
Environmental Efficiency	0.233	0.226

the M_0 model, comprising the three inputs: X_1: capital, X_2: labor and X_3: TOE and two outputs: Y_1: VA; Y_1: CO_2. The other model to be compared to M_0 model was called the M_1 model, comprising the three inputs: X_1: capital, X_2: labor, and X_3: TOE and two outputs: Y_1: GO; Y_1: CO_2. Table 7 shows the environmental efficiency results estimated M_0 model and M_1 model.

Fig. 1 shows changes in environmental efficiency during the study period. The environmental efficiencies in the two models are quite similar.

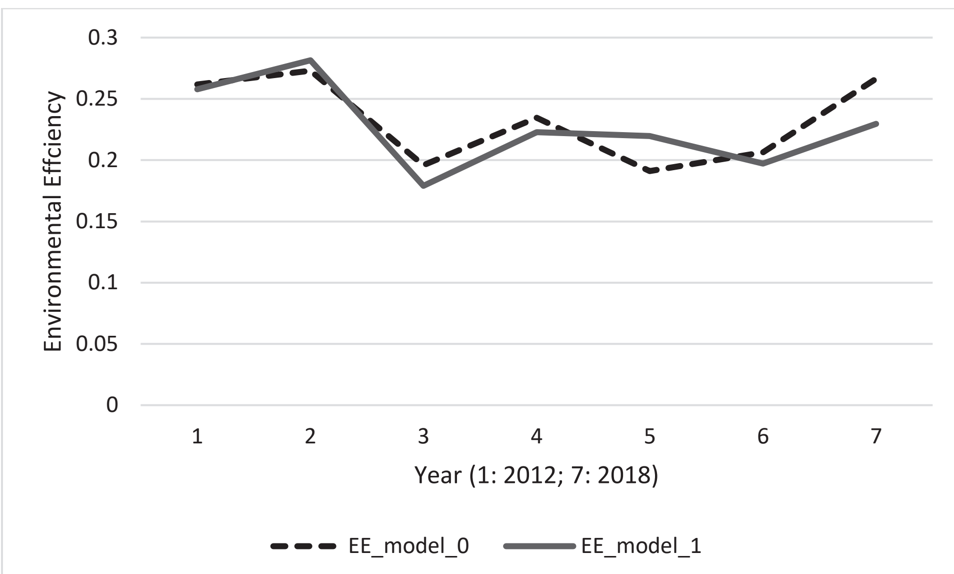
CONCLUSION

This study applied the Super-SBM DEA model, considering undesirable outputs, to estimate the environmental efficiency of the Vietnam textile and garment industry in the period 2012-2018. Then, the Tobit regression model is used to measure the impact of factors on environmental efficiency and test the stability of environmental efficiency rankings by using the Kruskal-Wallis H test. The empirical results show that (i) there has been a slight decrease in environmental efficiency over the years, at an average of 23.3%. (ii) Some factors, such as income per employee, machined imports from developed countries, industrial zones, firm improvement processes, and the presence of FDI, have positive effects on a firm's environmental efficiency, while materials made in Vietnam have a negative influence. (iii) There are great differences in environmental efficiency between the four scale groups. In which large-scale firms tend to be more efficient than small- and medium-scale firms. (iv) The government's policies to control CO_2 emissions from the textile and garment industry are still weak.

In conclusion, some suggestions for increasing environmental efficiency in the textile and garment industry are given as follows:

(i) Increase the attractiveness of industrial parks and economic zones in attracting investment and firm participation, develop eco-industrial parks, and transition traditional to ecological ones through preferential policies and incentives, because industrial parks, particularly eco-industrial parks, can help reduce CO_2 emissions for sustainable development in this industry. Some support policies that can be applied are tax exemption, reduction, land rent, and priority in credit loans for firms operating in eco-industrial parks.

(ii) Promote the development of technology imported from developed countries, encourage firms to access environmentally friendly technology, and prevent the import of technology harmful to the environment. The government strengthens the standards for importing used machinery by regulating the age of all used machinery to not exceed 10 years, improving national technical



Source: the author estimates from annual surveys of GSO.

Fig 1: Changes in environmental efficiency trend of two models.

regulations on safety, energy savings, and environmental protection to be on a par with global standards, and supporting or guaranteeing loans for imported advanced machinery from developed countries.

(iii) Regarding foreign investment, it is necessary to choose investors with a sustainable and environmentally friendly investment history to ensure environmental protection.

(iv) Encourage firms to regularly implement innovation and improvement processes to increase the quality of their products and apply advanced processes and tools in their production. Some solutions that can be applied are efficiency improvements in the internal cooperation process, increased receptive capabilities, and promotion of cooperation with other firms and institutions, especially FDI firms, via conferences, seminars, training courses, and consultations.

(v) Strengthen the environmental control by making CO_2 emission reduction policies such as environmental tax policies, managing chemicals and energy, raising firm awareness on using optimal materials, and increasing the enforcement capacity for implementing regulations of environmental protection.

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