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Synergy in environmental compliance, innovation and export on SMEs' growth

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Abstract

Although numerous studies examine the impacts of environmental compliance and innovation on a firm's economic performance, the role of export activities in this nexus has remained unanswered. In this study, we revisit the Porter hypothesis by investigating synergy strategies of different environmental and economic practices (i.e., environmental compliance, product innovation, process innovation and having export activities) on total factor productivity (TFP) of Vietnamese manufacturing SMEs. Our results suggest that while encouraging either product or process innovation is also essential in the environment-promoting policy, joint implementation of these two practices should be carefully considered by managers. Moreover, entering export markets positively impacts firms' productivity; complying with the domestic/local environmental standards could significantly increase the chances for SMEs to enter the export markets.

Keywords: Environmental compliance; Export; Product innovation; Process innovation; Productivity; SMEs.

JEL Classification: L25; M11; O12; Q55; Q56.

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1 Introduction

Environmental quality has been regarded as one of the most crucial factors in sustainable development. Since the 1990s, a traditional view of environmental regulation argued that the stringency of environmental regulation requiring firms to reduce an externality like pollution could significantly increase the production costs and thus reduce their profits (Simpson and Bradford III, 1996). Over the past twenty years, revisionists proclaimed that such environmental regulations could impose pressure and encourage firms to improve their efficiency in resource uses by investing in R&D (e.g., environmentally-friendly technologies) (Hamamoto, 2006; Yang et al., 2012; Rubashkina et al., 2015a). These studies suggested that it is possible to cope with environmental pollution by triggering innovation and thus improving productivity, which is also known as the “Porter hypothesis” (henceforth PH) (Porter, 1996; Porter and Van der Linde, 1995).

Recently, existing literature has shown that environmental regulation spurs R&D investment and thus has a significant positive effect on firms’ total factor of productivity (TFP). In other words, the results of these studies documented the complementarity of innovation and environmental regulation on TFP of manufacturing industries (Hamamoto, 2006; Ambec et al., 2013; Rubashkina et al., 2015a). Complementarity is understood to exist in this context if the deployment of one practice boosts the marginal or incremental return of other practices, while the implementation of one practice can decrease the marginal return of another practice is the case of substitutability (Mohnen and Röller, 2005; Mothe et al., 2015; Van Leeuwen and Mohnen, 2017). These studies indicated that environmental regulation stringency is not detrimental to productivity because stringent regulation could increase the pressure on R&D investment to improve pollution abatement and thus benefit firms’ performance (Iraldo et al., 2011; Rubashkina et al., 2015a; Fan et al., 2021).

In addition to the link between environmental compliance and innovation, the relationship between innovation and international trade, as well as its impacts on productivity, have also been widely documented. Some studies indicated that a nation increasing its competitiveness is to improve its productivity indices through strengthening its capacity for innovation (Lall, 2001; Kim et al., 2009). For instance, under intensive global market competition, firms trading on international markets are more likely to innovate by adsorbing advanced technologies in the foreign marketplace (Kim et al., 2009). Moreover, the global competitiveness of a firm or nation links to the proportion of R&D collaborations between industries at both firm and national levels (Scherngell et al., 2020; Sart and Artar, 2021).

While the complementarity of export and innovation on productivity has been widely studied, there is a handful of evidence on the role of export and environmental regulations in explaining TFP, especially for firms in developing countries. In particular, firms entering export markets are often associated with higher environmental compliance since their products must meet strict environmental standards/requirements to be successfully exported to international markets (Dasgupta et al., 2000). However, evidence suggested that stringent environmental regulations could harm firms' capacities to compete in global markets, especially for those in emerging countries (Dechezleprêtre and Sato, 2017). For instance, small and medium-scale enterprises (SMEs) in developing countries, which often need more technological innovations, better management skills, etc., are experiencing significant barriers to being qualified with the international standard and competing in the international markets. Therefore, the synergy between firms' environmental compliance and entering export markets needs to be carefully investigated.

In this study, we aim to contribute to the existing literature by evaluating the synergy in compliance with local environmental regulations, adopting process or product innovation, and entering export markets to explain SMEs' productivity. Notably, we revisit the validity of the PH for the case of SMEs and examine the 'extended' version of the PH by integrating the role of participation in export markets. In particular, firms with export activities are determined as participating and competing on global markets (Aulakh et al., 2000). Moreover, our study uses the data of manufacturing SMEs in Vietnam (i.e., DANIDA databases) to estimate firms' stochastic TFPs and then conduct the complementarity/substitutability test to analyze the impacts of pair synergies on TFPs. We focus on Vietnam as a good context for revisiting the validity of the PH because SMEs account for approximately 97% of the total number of enterprises and contribute more than 40% GDP (Phan et al., 2015). However, SMEs are also concerned as a primary contributor to environmental degradation in Vietnam (World Bank, 2016). For instance, in a UNDP official report on the local environmental performance index in Vietnam, the authors showed that most SMEs are small manufacturing centers using outdated technology, which may cause severe environmental degradation due to their unregulated structures and lack of supervision.

Several existing studies using DANIDA databases have suggested the crucial roles of investment in technology and innovation in promoting Vietnamese SMEs' productivity since innovation fosters SMEs' diversification efforts and thus enhances their competitiveness (Nguyen et al., 2018). Direct government support by incentivizing investments in technology and innovation is also proven to help enhance SMEs' productivity, especially for state-owned enterprises

(Tarp, 2017). Moreover, innovations are a critical determinant of exporting for Vietnamese SMEs. Pushing innovation activities is essential for an emerging economy like Vietnam to integrate into the global market via international trade (Nguyen et al., 2008).

Besides the roles of innovations on export and productivity, some studies using DANIDA databases also indicated the critical role of international and environmental standards on Vietnamese SMEs' productivity (Calza et al., 2019). For instance, the authors argued that implementing an international management standard could potentially facilitate the enhancement of their managerial and operational processes, leading to a subsequent increase in productivity (Calza et al., 2019). Thus, it is essential to improve the environmental consciousness of Vietnamese SMEs and the advantage of approaching environmental factors for firm performance to enable them to maintain their competitiveness in the increasingly competitive global and regional marketplaces (Tsai et al., 2021).

However, no evidence exists of the complementary/substitute of environmental standards, exporting and innovations on SMEs' productivity. Therefore, using DANIDA databases, this study appears uniquely to examine how these factors could complementarily/substitutely affect Vietnamese SMEs' performance, which is a critical research matter. A table summarizing existing literature using the DANINA database is presented in Table A5 in the Appendix.

The remainder of this paper is organized as follows. Section 2 discusses the study's background and literature review. The data, methodology and descriptive statistics are elaborated in Section 3. Section 4 analyzes the results in light of the relevant literature. Finally, Section 5 discusses the results and their policy implications.

2 Literature review

From the milestone work of Porter and Van der Linde (1995), several studies have been conducted to examine the relationship between environmental compliance and productivity (Jaffe and Palmer, 1997; Wagner, 2003; Brännlund and Lundgren, 2009; Rubashkina et al., 2015b). These studies argued that the PH should be represented in three versions: “weak”, “strong” and “narrow”. The “weak version” states that, to comply with environmental regulations, firms need to improve performance toward production efficiency by investing in R&D. The “strong version” posits that under stringent environmental regulations, the benefit from innovation offsetting the compliance costs could incentivize firms to invest in innovation. The “narrow version” postulates that flexible and well-designed market-based regulations could motivate firms to innovate rather than prescriptive regulations.

The PH consists of several tenets. Firstly, well-designed environmental policies could create a fair business environment since they prevent firms from taking advantage by not complying with environmental regulations. Secondly, well-designed environmental policies force inefficient firms to explore their potential capacity in resource use efficiency. Finally, such policies provide information/knowledge about environmental issues and thus help raise corporate awareness about the importance of environmental protection. For instance, pollution and intermediate material use may also be reduced simultaneously without decreasing productivity (Bernstein et al., 1990 and Boyd and McClelland, 1999).

In contrast, some studies asserted the conventional notions that environmental compliance could increase production costs and thus harm firms' profit (Ambec et al., 2013; Brännlund and Lundgren, 2009). However, this conventional view considers inefficiencies in the situation without dynamic spillovers of environmental regulations (Porter and Van der Linde, 1995). Moreover, these studies noted that the impact of environmental regulations associated with innovation and export on TFP is still ambiguous, especially in developing countries.

2.1 Productivity and environmental compliance

Most studies in this research area indicated a positive link between environmental compliance and productivity. For instance, "pollution abatement expenditure" is often used as a proxy of the level of environmental regulation stringency, demonstrating a positive impact on R&D investment and productivity (Hamamoto, 2006; Piot-Lepetit and Le Moing, 2007; Yang et al., 2012).

However, some other studies supported the "win-win" of the PH only in certain conditions (Russo and Fouts, 1997; Berman and Bui, 2001). For instance, costly environmental compliance forces firms to spend more on pollution abatement, which could reduce production efficiency (Shadbegian and Gray, 2006). Moreover, there is evidence that environmental stringency could negatively impact productivity (Barbera and McConnell, 1990; Shadbegian and Gray, 2005; Lanoie et al., 2008; Raff and Earnhart, 2022). In their study, the authors found that a costly pollution abatement and compliance in pollution-intensive industries could cause a significant reduction in TFP (Conrad and Wastl, 1995; Simpson and Bradford III, 1996). Thus, environmental policy designs could motivate firms to efficiently reallocate their production to reduce the environmental impacts (Becker, 2011; Rubashkina et al., 2015b; Van Leeuwen and Mohnen, 2017).

In developing countries like Vietnam, SMEs lack financial capital, know-how, access to appropriate technology, etc. Thus, environmental stringency forces them to invest in costly

pollution abatement, which could harm their productivity. Therefore, we could hypothesize that:

Hypothesis 1: Compliance with stringent environmental regulations could negatively impact the productivity of SMEs.

2.2 Environmental compliance and innovation

Following the PH, several studies suggested environmental regulations could incentivize firms to innovate and thus positively impact their performance/productivity (Jaffe and Palmer, 1997; Hamamoto, 2006; Horbach, 2008; Yang et al., 2012; Van Leeuwen and Mohnen, 2017). These studies argued that well-designed regulations and flexible environmental mechanisms motivate inefficient firms to improve their capacity by investing in human resources, technological innovation and R&D (Jaffe and Palmer, 1997; Eiadat et al., 2008). For instance, a study indicated that a significant reduction of toxic emissions in the U.S. results from green innovation policies and flexible environmental regulations (Carrión-Flores and Innes, 2010).

However, the effectiveness of green investment on productivity depends on the types of innovation (Rennings and Rammer, 2011). For instance, environmental regulations could, on the one hand, motivate firms to adopt new energy-saving technology to reduce unexpected outputs (i.e., process innovation) (Zhang et al., 2011). On the other hand, such regulations encourage firms to innovate new environmentally-friendly products (i.e., green products) that are highly appreciated by customers and thus generate higher market value (i.e., product innovation) (Dowell et al., 2000; Kammerer, 2009).

Vietnam is considered a typical case of transition economies, where the link between environmental compliance and economic performance associated with innovation has remained speculative and under-explored, particularly for SMEs. Product innovation (i.e., investing in green products) could help SMEs take advantage of the growing demand for environmentally-friendly products that generate higher market value. For instance, in a study examining the relationship between green product innovation and firm performance of four foreign motorcycle companies in Vietnam, the authors demonstrated that market demand for green product innovation is highly associated with green product innovation and firms' performance (Lin et al., 2013). Therefore, we could hypothesize that:

Hypothesis 2: There is a complementarity between environmental compliance and product innovation on SMEs' productivity.

Moreover, Vietnamese SMEs face difficulties in process innovation since they lack both

physical and human capital. Hence, their capacity for technological improvement is low, and they need support for investment in environmentally proactive technology (Dieu, 2006). Therefore, we could hypothesize that:

Hypothesis 3: There is no link between environmental compliance and process innovation on SMEs' productivity.

2.3 Innovation and export

The theory of international trade argues that the global market provides firms opportunity for financing R&D investment (Grossman and Helpman, 1990). Additionally, firms could benefit from knowledge spillovers since ideas and information could spread rapidly and costlessly through communication across international borders (Grossman and Helpman, 1990; Santacreu, 2015). Particularly, through trade (i.e., import and export), domestic producers could adopt foreign technology embedded in the imported intermediate goods to improve their research productivity, which requires long-term resource investment and learning over time.

Moreover, to compete in global markets, firms are required to produce environmentally-friendly products with strict international standards. As a result, local firms have to put efforts into both product and process innovation. Thus, complying with international regulations stimulates firms' innovation in product quality, production capacity, brand name and export competitiveness (Porter and Van der Linde, 1995; Bigliardi et al., 2012; Costantini et al., 2013). Evidence indicated a positive relationship between product quality and export volume (Roy, 2012). For instance, a study in the US suggested that exporters have 9 - 13% lower emissions than non-exporters across numerous industries (Holladay, 2016). This is because exporters require firms to improve their environmental abatement (i.e., reduce emissions) by investing in new environmentally-friendly technology (Batrakova and Davies, 2012; Chakraborty, 2012). Therefore, we could hypothesize that:

Hypothesis 4: There is a complementarity between innovation (both in product and process) and entering export markets (i.e., export) on SMEs' productivity.

2.4 Environmental compliance and export

Environmental regulations are a critical driver to encourage firms' innovation and performance. Stringent local environmental policies could also improve firms' capacity to enter the international market. For instance, countries with strict standards are more likely to become surplus exporters than other countries (Costantini and Crespi, 2008). Some studies also found a negative

relationship between being exporters and pollution emissions (Copeland et al., 1995; Copeland and Taylor, 2005). Moreover, international businesses are more willing to trade with those in countries with stringent environmental regulations (i.e., putting effort into protecting the environment) than others (Prakash and Potoski, 2006). Thus, there is evidence that firms complying with strict environmental regulations have an opportunity to become exporters and elevate their performance. Therefore, we could hypothesize that:

Hypothesis 5: There is a complementarity between environmental compliance and entering export markets (i.e., export) on SMEs’ productivity.

3 Data and method

3.1 Methodology

The methodology includes three different parts: (i) TFP estimates; (ii) Impacts of synergy strategies on TFP; (iii) Supermodularity and submodularity test. Firstly, we adopt the Wooldridge (2009)’s method to estimate the stochastic total factor of productivity (TFP). While the previous study suggested a two-stage estimation of productivity (Akerberg et al., 2015), Wooldridge (2009) argued this two-stage estimation has some disadvantages: (1) they ignore the error term in the first stage, which could reduce the estimation efficiency; (2) the problem of serial correlation is highly likely. Woodridge proposes an alternative method with one-step estimation using the generalized method of moments (GMM) based on previous TFP estimation methods of Olley and Pakes (1996); Levinsohn and Petrin (2003); Akerberg et al. (2015) with one-step estimation using the generalized method of moments (GMM). Detailed methodology is discussed in Appendices B and E.

Secondly, the fixed-effect with instrument variable (IV-FE) model is chosen as the best model to assess the impact of environmental compliance and its combinations with innovation and export on TFP. In this study, each firm decides to choose four different practices, including “Environmental compliance” (*Environment*), “Product innovation” (*Product*), “Process innovation” (*Process*) and “Having export activities” (*Export*). Based on the assumption that a firm i decides to choose a synergy strategy g such that

$$\max_g \Psi_{it}(s_{i,g}, \phi_{it}),$$

where $\Psi_{it} \equiv \ln TFP_{it}$. Thus, there are totally 16 different possible synergy strategies (See the details in Table A4 in the Appendix).

The impacts of different synergy strategies on TFP can be written as the following regression

function:

$$\Psi_{it} = \sigma_0 + \sum_{g=0}^{15} \gamma_g s_{i,g} + X'_{it}\theta + Z'_{it}\phi + \mu_i + \varepsilon_{it}, \quad (1)$$

where $s_{i,g}$ is the vector of binary variables representing the strategies chosen by firm i ; X'_{it} is a set of time-varying control variables (e.g., abatement cost, firm size); Z'_{it} is a set of time-invariant control variables, including technological sectors and industrial zone; μ_i and ε_{it} are individual and time-specific unobservable effect.

The Hausman-Taylor (HT) estimator is applied as an alternative to the model fixed effect with instrumental variable (IV-FE) because of its advantages. The HT estimator allows us to control for time-constant and time-varying variables that could correlate with the individual-specific unobservable effect μ_i . More precisely, we used X'_{it} as a set of time-varying control variables, such as a log of abatement cost and firm size and Z'_i as a set of time-invariant control variables, such as technological sector and industrial zone. The HT estimator would be more efficient than others if there exist correlations between S_g , X_{it} , Z_{it} and μ_i , $E(\mu_i|S_g, X_{it}, Z_{it}) \neq 0$. The Hausman test is used to compare efficient and consistent performance for each of these estimators to select the best estimation model.

Finally, the complementarity and substitutability tests are conducted to test the complement and substitute relationship between different synergy strategies (i.e., environmental compliance, product innovation, process innovation, having export activities). The existing literature has suggested that because of the correlation between indicators comprising the synergies, the statistical significance of synergies coefficients could not be concluded separately (Mohnen and Röller, 2005; Mothe et al., 2015). Thus, the supermodularity and submodularity tests are useful to analyze the relationship between different practices comprising the synergy strategies using their linear inequality restriction and joint distributions (Milgrom and Roberts, 1990, 1995; Mohnen and Röller, 2005; Mothe et al., 2015; Van Leeuwen and Mohnen, 2017). See the details in Appendix E.

3.2 Data

This study uses the biannual survey data carried out by the collaboration between the Institute of Labour Studies and Social Affairs (ILSSA), Vietnamese Ministry of Labour, Invalids and Social Affairs (MOLISA) and the University of Copenhagen, funding by DANIDA.¹ The survey collected data from the Vietnamese SMEs in ten provinces: Hanoi, Ho Chi Minh City, Long An, Lam Dong, Hai Phong, Binh Dinh, Khanh Hoa, Nghe An, and Binh Duong. Several surveys

¹DANIDA is the Royal Embassy of Denmark in Vietnam.

were conducted every two years from 2005-2015, with 2,500 firms per wave. The dataset covers information on firms’ characteristics, production, forms of ownership, trade, etc. Our data is based on five survey waves from 2007-2015 because information related to firms’ environmental compliance is available only from 2007. After eliminating responses with missing observations, we have an unbalanced panel of 4,430 firms and 12,369 observations.

3.3 Descriptive statistics

Table 1 reports our variable definitions and their descriptive statistics. It can be seen that only 14% of firms in our sample claimed that they had been certificated with the official Environmental Standard Certificate (i.e., “ESC”). Nearly 35.72% of firms stated that they were implementing product innovation (e.g., creating a new product or improving an existing one), while only 10.68% of them implemented process innovation (e.g., implementing a new or improved production process). Table 1 also shows a slightly low ratio of SME firms having export activities, about 6%.

Concerning control variables, most SME owners reported that they do not care about environmental law, with only 14.03% of owners having a good and average level of knowledge about environmental law. We observe that most SMEs in our sample (69.49%) belong to micro SMEs (i.e., firms that have 1 - 9 employees), and only around 6.03% of them are medium-scale firms (see Table 2). Regarding the technological sector, firms that belonged to the low technological sector accounted for the highest ratio (i.e., 65.29%), while there were only 28.92% of SMEs in the medium technological sector and 5.68% of SMEs in the high technology sector. Furthermore, Table 2 indicates that around 5.13% of SMEs are in industrial and special processing zones.

Denote the synergy in “Environmental compliance”, “Product innovation”, “Process innovation”, and “Having export activities” are s_{abcd} , where a,b,c,d are *Environment*, *Product*, *Process*, and *Export*, respectively; and $a, b, c, d = \{0, 1\}$. The distributions of these strategies are reported in Table A1 (in Appendix A). Table A1 (in Appendix A) suggests that s_{0000} , on average, equals 0.521, indicating that more than 50% of SMEs in our sample had not implemented any environmental and economic practices. Firms adopting only product innovation account for 22.8%, while only 1% of firms only implemented process innovation, suggesting that SMEs’ innovation strategies focus on developing new products and improving existing product lines rather than on processes. More importantly, a small portion of SMEs applied all environmental and economic practices with only 0.6%.

Table 1: Variable definitions and descriptive statistics.

Variables	Definition	Mean	Std.	Min	Max
Environment	=1 if a firm had been certificated with an Environmental Standard Certificate (ESC).	0.140	0.347	0	1
Product	= 1 if a firm had implemented a product innovation (e.g., creating a new product or improving an existing one).	0.357	0.479	0	1
Process	= 1 if a firm had implemented a process innovation (e.g., implementing a new or improved production process).	0.107	0.309	0	1
Export	=1 if a firm had export activities.	0.060	0.238	0	1
Control variables					
KEL	= 1 if a firm's Knowledge about Environmental Law is above the average level.	0.187	0.390	0	1
lnAbacost	Log of abatement cost spending on abatement activities.	0.299	0.719	0	7.956
Firm size	=1 if a firm had less than 9 workers, =2 if there are 9 to 49 workers and =3 for 49 to 300 workers.	1.365	0.594	1	3
Tech sector	= 1 if a firm was in a low technological sector, =2 for medium-low technological sector and =3 for a medium-high technological sector.	1.404	0.595	1	3
Industrial zone	= 1 if a firm is located in an industrial zone, processing zone or special economic zone.	0.051	0.221	0	1
Y	Valued added (1 million VND)	326	1,416	-978	87,178
K	Total physical asset (1 million VND)	1,165	4,157	0	158,485
L	Labor	14	27	0	300
M	Material cost (1 million VND)	1,224	22,903	-207	2,269,122

Table 2: Descriptive statistics across years from 2007 - 2015.

Indicators	2007	2009	2011	2013	2015	Average
Environment (%)	8.73	13.56	16.13	19.04	12.95	14.03
KEL:						
-Good and average	18.35	18.85	21.35	18.79	16.52	18.74
-Poor and not concern	81.65	81.15	78.65	81.21	83.48	81.26
Innovation:						
-Product	45.91	42.21	40.58	16.83	32.62	35.72
-Process	15.16	13.91	13.12	6.42	4.90	10.68
Export	5.30	5.81	5.98	6.25	6.80	6.03
Firm size:						
-Micro	66.77	67.11	68.58	71.96	72.98	69.49
-Small	26.69	26.36	25.41	22.46	21.27	24.48
-Medium	6.27	6.52	6.02	5.58	5.75	6.03
Tech sector:						
-Low	63.99	64.70	65.40	65.96	66.41	65.29
-Medium	29.43	29.76	28.88	28.38	29.03	28.92
-High-low	6.59	5.53	5.73	5.67	4.90	5.68
Industrial zone	6.31	5.18	4.76	5.42	4.00	5.13
Number of observations (N)	2,474	2,530	2,393	2,400	2,572	12,369

Source: Calculating from data set SMEs.

4 Estimation results

The estimation is separated into three parts: TFP estimates, the impacts of synergy strategies on TFP and the complementarity/substitutability test for testing the relationship of practices in the synergy strategies.

TFP estimates

In the first part, the method proposed by [Wooldridge \(2009\)](#) is applied to estimate the SMEs' TFP in our data. [Table 5](#) shows the estimation result of the Wooldridge productivity estimator with the Cobb-Douglas production function. We observe that both capital and labor inputs have a significant impact on SMEs' TFP. The results also indicate that "Capital inputs" (K) have a lower significant impact than "Labor inputs" (L) on productivity. This result aligns with the existing literature that labor is more critical to firms' productivity than capital, especially for small- and medium-scale firms ([Cobb and Douglas, 1928](#)).

Table 3: Wooldridge estimation of the production function.

	Coef.	Std. Err.
ln L	0.711	0.007
ln K	0.172	0.005
Hansen's J statistics	385.71	
Hansen's J p -value	0.00	
Number of observations	12427	
Number of firms	4430	

Impact of synergy strategies on TFP

In the second part, the impacts of synergy strategies on TFP are estimated using different methods, including Fixed Effects (FE), Random Effects (RE), Instrumental Variable-Fixed Effects (FE-IV), and Hausman-Taylor (HT). The Hausman-Taylor was selected as the best estimator. Note that the Hausman test is also used to test different model specifications (see [Appendix D](#)). The estimation results of synergy strategies on TFP using other methods (i.e., RE and FE) are reported in [Table A3](#) (in [Appendix A](#)).

[Table 4](#) presents the estimation results using FE-IV and Hausman-Taylor estimators.

Table 4: Estimation results of synergy strategies on TFP.

	IV-FE		Hausman-Taylor	
	Coefficients	Std. Error	Coefficients	Std. Error
$s_{i,0001}$	0.283**	0.093	0.412***	0.073
$s_{i,0010}$	0.096	0.068	0.049	0.048
$s_{i,0011}$	0.449*	0.178	0.472**	0.181
$s_{i,0100}$	0.089**	0.033	0.080***	0.018
$s_{i,0101}$	0.310***	0.078	0.420***	0.064
$s_{i,0110}$	0.111*	0.052	0.095**	0.032
$s_{i,0111}$	0.405***	0.108	0.542***	0.087
$s_{i,1000}$	0.572	0.042	0.156***	0.033
$s_{i,1001}$	0.436*	0.193	0.449***	0.083
$s_{i,1010}$	0.494*	0.230	0.304***	0.090
$s_{i,1011}$	0.895***	0.266	0.900***	0.195
$s_{i,1100}$	0.532	0.375	0.231***	0.046
$s_{i,1101}$	0.467*	0.186	0.556***	0.108
$s_{i,1110}$	0.334	0.233	0.158**	0.060
$s_{i,1111}$	0.552**	0.196	0.584***	0.106
lnAbacost	0.007	0.019	0.059***	0.012
Small size	-0.021	0.026	0.392***	0.018
Medium size	-0.054	0.053	0.546***	0.036
Medium Tech			0.177***	0.017
High-low Tech			0.196***	0.031
Industrial zone			0.111***	0.030
Year 2009	0.067***	0.024	0.092***	0.018
Year 2011	0.170***	0.030	0.190***	0.020
Year 2013	0.156***	0.044	0.204***	0.021
Year 2015	0.205***	0.028	0.230***	0.022
Intercept			1.704***	0.018
Observations	12,369		12,369	
Number of firms	4,430		4,430	
F Statistic	1.396 ($df = 22; 7922$)		399.99*** ($df = 25; 12343$)	

Notes: Estimation based on the Hausman-Taylor estimator. The dependent variable is $\ln TFP$. The reference category is $s_{i,0000}$.

Significance level: * $p < 10\%$, ** $p < 5\%$, *** $p < 1\%$.

The results suggest that all coefficients of our synergy strategies have significant impacts on TFP, except for $s_{i,0010}$. Note that $s_{i,0010}$ is the situation in which firms implemented only process innovation. Notably, the coefficient associated with *Environment* (s_{1000}) is statistically significant (p-value < 0.05) and 15.6% higher than that of the reference category. This result suggests that firms would perform better by applying synergy strategies than the baseline, where firms did not implement any practices. These findings are in vein with previous studies that complying with environmental regulations (e.g., air regulations, regulations on water discharge) positively impacts firms' productivity and competitiveness (Berman and Bui, 2001; Piot-Lepetit and Le Moing, 2007; Rubashkina et al., 2015b). Thus, we could conclude that Hypothesis 1 is not satisfied.

While product innovation could significantly impact firms' TFPs, firms that implement only process innovation do not significantly impact productivity. This result suggests that Vietnamese SMEs should focus on product innovation (e.g., diversifying and innovating new products) rather than process innovation (e.g., implementing a new or improved production process) to improve production efficiency (Hamamoto, 2006; Horbach, 2008; Rubashkina et al., 2015a). Regarding the relationship between exports and TFP, export activities are vital in determining firms' productivity. This result could be explained by the fact that export activities could indirectly enhance productivity through their positive spillovers on environmental performance (Galdeano-Gómez, 2010).

Regarding the control variables, Table 4 shows that all control variables have positive and statistically significant impacts on TFP. This result suggests that the positive effects of higher levels of investment in environmental abatement, larger firm size, higher technological sectors and industrial zones could be significant factors that influence SMEs' performance.

Supermodularity and submodularity tests

This section reports the results of the supermodularity and submodularity tests are reported (see Table 5). Note that the test statistics are calculated based on the coefficient estimates of the Hausman-Taylor model in Table 4.

Table 5 indicates supermodularity of $(a-b)$ is accepted, and submodularity of $(a-b)$ is inconclusive, suggesting the complementarity between environmental compliance ("*Environment*") and product innovation ("*Product*") $(a-b)$ on productivity. This finding is consistent with the results of previous studies that strict regulation could incentivize firms to invest in innovative activities (Jaffe and Palmer, 1997; Horbach, 2008; Bigliardi et al., 2012; Rubashkina et al., 2015b). For instance, Bigliardi et al. (2012) shows that firms with eco-innovations have higher

Table 5: Complementarity and substitutability tests.

Pairs	Kodde-Palm test statistics					
	a - b	a - c	a - d	b - c	b - d	c - d
Supermodularity (Complementarity)	0.518 ^A	3.060 ^N	0.380 ^A	0.090 ^A	0.077 ^A	3.537 ^N
Submodularity (Substitutability)	4.706 ^N	1.837 ^N	1.670 ^N	7.805 ^R	1.428 ^A	0.000 ^A

Note: The Kodde-Palm test statistics are computed based on the results of Table 4. Practices a, b, c, and d stand for “Environmental compliance”, “Product innovation”, “Process innovation” and “Having export activities”, respectively. The lower and the upper bounds are calculated at the 10% level of significance are 1.642 for $df = 1$ and 7.094 for $df = 4$ (Kodde and Palm, 1986).

performance compliance and better perception of environmental beliefs, which could accrue spending on R&D, enhancing innovation performance. Therefore, Hypothesis 2 is satisfied.

However, supermodularity and submodularity of $(a - c)$ are inconclusive, indicating that simultaneously implementing environmental compliance and process innovation could not significantly enhance productivity. This finding suggests that jointly implementing environmental compliance and process innovation might not incentivize firms to improve productivity rather than separately adopting environmental compliance and process innovation. Therefore, Hypothesis 3 is satisfied.

Furthermore, the binary strategy between product and process innovations $(b - c)$ is complementary, suggesting that process innovation should be complemented by product innovation to ensure substantial profits from innovation. The other strategies, the synergy of “Product innovation” and “Export” $(b - d)$ and synergy of “Process innovation” and “Export” $(c - d)$, are inclusive and substitute, respectively. These results imply that the joint implementation of process innovation and export could have a substitute impact on TFP. Therefore, Hypothesis 4 is not satisfied.

The complementarity between *Environment* and *Export* $(a - d)$ is also confirmed since both supermodularity is accepted and supermodularity is inclusive. This result suggests that joint implementation of environmental compliance and export activities could significantly impact productivity. Therefore, Hypothesis 5 is not validated.

5 Discussions and conclusions

Our study is the pioneer to empirically examine the synergy in different environmental and economic practices, such as environmental compliance, product innovation, process innovation and

having export activities on firms' stochastic TFPs using the supermodularity and submodularity tests. Our findings partially support the Porter Hypothesis, in which environmental compliance can complement product innovation in enhancing firms' TFP, while the joint implementation of environmental compliance and process innovation to promote production efficiency is inconclusive. Evidence suggests that stringent environmental regulations motivate firms to invest in product innovation (e.g., new environmentally-friendly products) (Rehfeld et al., 2007; Amores-Salvadó et al., 2014; Peters and Buijs, 2022). Through green product innovation, firms could enhance their competitiveness by gaining higher market share and limiting their environmental burdens (i.e., cost reductions) (Hamamoto, 2006; Triebswetter and Wackerbauer, 2008). As a result, environmentally-induced R&D could improve product innovation, significantly impacting firms' productivity.

However, the compatibility of environmental compliance with process innovation is ambiguous since our result indicates that joint implementation of process innovation and environmental compliance could not significantly improve productivity. This result is in line with the existing literature that the environmental innovation goals are not always a key factor for process innovation because environmental protection at the process level provides little additional benefit to the consumer and thus receives a little reward from the market compared to product innovation (Clegg and Rennings, 1999; Kammerer, 2009; Chien et al., 2022). Moreover, SMEs in developing countries like Vietnam lack financial capital, skillful workers, and know-how about technological processes. Thus, process innovation requires the necessary human resources and technology conditions, considered one of the most crucial SMEs' obstacles (Hervas-Oliver et al., 2016). Therefore, SMEs are more likely to prefer product innovation to process innovation.

We observe that the synergy in product innovation and having export activities on productivity is inclusive, while the combination of process innovation and export is a substitute in explaining firms' TFP. Thus, SMEs should implement these two practices separately, "Process innovation" and "Having export activities" in isolation. The existing literature has suggested that the basis of the complementary between innovation and exports is firms' knowledge about foreign markets and ability to learn from export, which is the obstacle of SMEs in developing countries (Golovko and Valentini, 2011; Bratti and Felice, 2012; de Oliveira et al., 2021). Moreover, successful exported firms need to promote information dissemination, product differentiation, brand building, etc., to herald the value of their innovative products (Golovko and Valentini, 2011). Therefore, although exports and innovation could be perceived as substitute strategies, combining the two strategies should be carefully considered by managers.

Our result suggests that entering export markets positively impacts firms' productivity;

complying with the domestic/local environmental standards could significantly increase the chances for local firms to enter the export markets. Understanding the good impact of local environmental certifications in Vietnam is facilitated by the fact that environmental pollution and food safety have become major issues in contemporary Vietnamese social and political debate (Wertheim-Heck et al., 2015; Calza and Goedhuys, 2021). In this context, awarded an environmental standard certificate (ESC) is an essential signal for consumers, such as higher quality of foods/products and better environmental control treatments (Christmann and Taylor, 2006). Moreover, local environmental certificates can serve as an intermediary step to signal quality, which is the first stage of preparation for adopting an international environmental certificate (Husted et al., 2016; Calza and Goedhuys, 2021). Thus, high product quality and low contamination levels could help reduce the chances of product detention and rejection at the borders, affecting Vietnam's reputation among its trading partners.

Policy implications

These results may provide policy implications. For instance, policies promoting SMEs' environmental compliance should be accompanied by policies encouraging firms to strengthen product innovation and foster process innovation. Meanwhile, export activities should be promoted in correspondence with a product innovation prompting program.

Some possible implications for entrepreneurs and policymakers from this study might be as follows. Firstly, policies aiming at promoting firms to comply with environmental regulations should differ across different types of firm scales and sectors (Fang et al., 2020; Liu et al., 2021). Secondly, policies that promote firms' environmental compliance to encourage innovation, especially product innovation, should be considered (Golovko and Valentini, 2011; Bratti and Felice, 2012; Ramanathan et al., 2017; Nie et al., 2021). For instance, policies encouraging intellectual property rights protection by constitutional provisions and laws could promote SMEs' R&D intensive, and thus help strengthen R&D-promoting policy (Carbonara et al., 2021). Thirdly, subsidy-supporting policies to increase process innovation performance are desirable to be implemented because of their substitute effects in combination with environmental compliance and export activities. Fourthly, promoting the diffusion of local/domestic environmental certificates could foster SMEs' growth and open opportunities for local SMEs to achieve international standards associated with high entry to international markets (Christmann and Taylor, 2001). Finally, consistent with the most crucial task that needs to be implemented presented in the report "Vietnam 2035" by The World Bank (World Bank, 2016), information and knowledge relevant to environmental protection should be disseminated, including the environmental law,

sustainable development strategies, the crucial role of environmental compliance in enhancing firms' productivity, rights and liability of enterprises and consumers in environmental protection, etc. This might nurture and create well-knowledge environmental perception, stakeholders' behaviors, and social norms, which are expected to play a vital role in sustainable development (Anand et al., 2021; Nguyen-Van et al., 2021; Zhang et al., 2022).

Limitations and further research

There are, of course, limitations of our analysis that must be considered when interpreting the findings of the results. Firstly, due to the constraint of data (i.e., DANIDA databases), our study only focuses the analysis on Vietnamese SMEs; therefore, the variance in the results of other emerging and industrialized countries may be significant and require retesting to apply and get a more complete picture in future studies. Secondly, the theoretical framework of complementarities in productivity, innovation and export remains under construction. Therefore, more effort should be put into conceptualizing the relationships between complementary practices and firm performance, especially as most studies of such complementarities remain empirical. Thirdly, our study has not yet considered moderator variables, such as internalization and innovation performance, which may be interesting to incorporate into the model. In other words, SMEs should reach a certain level of internationalization and be able to access a diverse variety of markets in order to reap the full benefits of their product and process innovation (Leung and Sharma, 2021). Finally, it would be interesting for future studies to look at the impacts of these practices on certified and non-certified firms' TFP. As corruption is common, there is a risk that Vietnamese firms will pay "informal costs" for innovation and export activities or obtain environmental certification without proper compliance. Therefore, much work remains to comprehend the complementary effects of organizational practices on SMEs' performance.

Competing interests

The authors declare no competing financial interests.

Data and code availability

The data and statistical codes (in R) used in this study are available from the authors upon request.

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Appendix A: Tables

Table A1: Distribution of synergy strategies.

Strategies	Mean	St. Dev.	Min.	Max.	Obs.	Freq.(%)
$s_{i,0000}$	0.521	0.500	0	1	6,450	52.15
$s_{i,0001}$	0.014	0.118	0	1	175	1.41
$s_{i,0010}$	0.019	0.137	0	1	238	1.92
$s_{i,0011}$	0.001	0.035	0	1	15	0.12
$s_{i,0100}$	0.228	0.420	0	1	2824	22.83
$s_{i,0101}$	0.016	0.126	0	1	198	1.60
$s_{i,0110}$	0.053	0.223	0	1	650	5.26
$s_{i,0111}$	0.007	0.082	0	1	84	0.68
$s_{i,1000}$	0.070	0.256	0	1	870	7.03
$s_{i,1001}$	0.010	0.098	0	1	121	0.98
$s_{i,1010}$	0.005	0.073	0	1	67	0.54
$s_{i,1011}$	0.001	0.035	0	1	15	0.12
$s_{i,1100}$	0.028	0.164	0	1	344	2.78
$s_{i,1101}$	0.005	0.073	0	1	66	0.53
$s_{i,1110}$	0.015	0.120	0	1	180	1.46
$s_{i,1111}$	0.006	0.076	0	1	72	0.58
Number of observations					12,369	
Number of firms					4,430	

Table A2: First-stage IV estimation for Environment.

	Coef.	Std. Err.
KEL	0.032***	0.007
Product innovation	-0.012*	0.006
Process innovation	-0.002	0.009
Export	0.072***	0.018
lnAbatement cost	0.055***	0.005
Small size	0.018*	0.011
Medium size	0.041*	0.022
Year 2009	0.058***	0.007
Year 2011	0.072***	0.008
Year 2013	0.115***	0.008
Year 2015	0.067***	0.008
Number of observations		12,369
Number of firms		4,430
Adjusted R^2		-0.457
F Statistic	50.677*** ($df = 12; 7933$)	

Notes: Estimation for First stage IV regression. The dependent variable is *Environment*. Significance level: *p < 10%, **p < 5%, ***p < 1%.

Table A3: Determinants of TFP, using various estimators.

	FE		RE	
	Coef.	Std.err	Coef.	Std.err
$s_{i,0001}$	0.204**	0.067	0.376***	0.053
$s_{i,0010}$	0.031	0.044	0.120**	0.041
$s_{i,0011}$	0.377*	0.165	0.467**	0.159
$s_{i,0100}$	0.069***	0.016	0.123***	0.015
$s_{i,0101}$	0.248***	0.059	0.366***	0.049
$s_{i,0110}$	0.058*	0.029	0.178***	0.027
$s_{i,0111}$	0.316***	0.080	0.542***	0.071
$s_{i,1000}$	0.073*	0.030	0.147***	0.025
$s_{i,1001}$	0.218**	0.077	0.399***	0.064
$s_{i,1010}$	0.229**	0.082	0.309***	0.077
$s_{i,1011}$	0.656***	0.178	0.767***	0.163
$s_{i,1100}$	0.134**	0.042	0.234***	0.037
$s_{i,1101}$	0.275**	0.100	0.457***	0.085
$s_{i,1110}$	0.057	0.055	0.181***	0.049
$s_{i,1111}$	0.344***	0.098	0.505***	0.083
lnAbacost	0.026*	0.011	0.088***	0.010
Small size	-0.011	0.024	0.338***	0.017
Medium size	-0.042	0.051	0.495***	0.034
Medium Tech			0.169***	0.018
High-low Tech			0.183***	0.032
Industrial zone			0.115***	0.030
Year 2009	0.087***	0.016	0.109***	0.016
Year 2011	0.198***	0.018	0.203***	0.017
Year 2013	0.205***	0.019	0.239***	0.018
Year 2015	0.228***	0.020	0.266***	0.018
Constant			1.688***	0.017
Number of observations	12,369		12,369	
Number of observations	4,430		4,430	
Adjusted R^2	-0.501		0.240	
F Statistic	14.564*** ($df = 22; 7922$)		157.066*** ($df = 25; 12343$)	

Notes: Estimation based on FE, RE, IV-FE estimator. The dependent variable is lnTFP. Significance level: *p < 10%, **p < 5%, ***p < 1%.

Appendix B: TFP estimation method

To estimate the firm's TFP, we start with the Cobb-Douglas production function:

$$Y_{it} = A_{it}K_{it}^{\beta_k}L_{it}^{\beta_l} \quad (2)$$

where Y_{it} is output of firm i ($i = 1, \dots, N$) at period t ($t = 1, \dots, T$), and A_{it} , K_{it} , L_{it} are TFP, capital stock and labor, respectively. The firm's TFP can be expressed as $A_{it} = A_0 \exp(\omega_{it} + \varepsilon_{it})$ where ε_{it} is the error term and ω_{it} the stochastic productivity shock.

Taking logarithm of Equation (2) gives:

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + \omega_{it} + \varepsilon_{it} \quad (3)$$

where $\beta_0 = \ln A_0$, $\ln Y = y$, $\ln K = k$ and $\ln L = l$. In addition, the productivity function could be derived as follows:

$$\omega_{it} = \omega(k_{it}, m_{it}) \quad (4)$$

where m_{it} is intermediate inputs.

Assume that

$$E(\varepsilon_{it} | l_{it}, k_{it}, m_{it}) = 0 \quad t = 1, \dots, T \quad (5)$$

then we have the following regression function:

$$\begin{aligned} E(y_{it} | l_{it}, k_{it}, m_{it}) &= \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \omega(k_{it}, m_{it}) \\ &= \beta_l l_{it} + f(k_{it}, m_{it}) \end{aligned}$$

where $f(k_{it}, m_{it}) = \beta_0 + \beta_k k_{it} + \omega(k_{it}, m_{it})$

To identify β_l , we need three assumptions. The first concerns ε_{it} such that Equation (5) could be derived as:

$$E(\varepsilon_{it} | l_{it}, k_{it}, m_{it}, l_{it-1}, k_{it-1}, m_{it-1}, \dots, l_{i1}, k_{i1}, m_{i1}) = 0 \quad t = 1, \dots, T$$

The second assumption is to restrict the dynamic in the productivity process:

$$E(\omega_{it} | \omega_{it-1}, \dots, \omega_{i1}) = E(\omega_{it} | \omega_{it-1}) \quad t = 2, \dots, T$$

The third assumption is that k_{it} is uncorrelated with the productivity innovation (τ) derived as follows:

$$\tau_{it} = \omega_{it} - E(\omega_{it} | \omega_{it-1})$$

In the second stage, the conditional expectation applied to find β_k depends upon (k_{it-1}, m_{it-1}) . Therefore, τ_{it} must be uncorrelated with (k_{it-1}, m_{it-1}) and then a sufficient condition could be formulated as:

$$E(\omega_{it} | l_{it}, k_{it}, m_{it}, l_{it-1}, k_{it-1}, m_{it-1}, \dots, l_{i1}, k_{i1}, m_{i1}) = E(\omega_{it} | \omega_{it-1}) = f[\omega(k_{it-1}, m_{it-1})]$$

Notice that components of l_{it} are allowed to be associated with τ_{it} . Then, the production function can be driven as:

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + f[\omega(k_{it-1}, m_{it-1})] + \tau_{it} + \varepsilon_{it}$$

Hence, to find β_k and β_l , two functions are derived below:

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + \omega(k_{it}, m_{it}) + \varepsilon_{it} \quad t = 1, \dots, T$$

and

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + f[\omega(k_{it-1}, m_{it-1})] + u_{it} \quad t = 2, \dots, T$$

where $u_{it} \equiv \tau_{it} + \varepsilon_{it}$. The orthogonal conditions are stated as follows:

$$E(u_{it} | k_{it}, l_{it-1}, k_{it-1}, m_{it-1}, \dots, l_{i1}, k_{i1}, m_{i1}) = 0 \quad t = 2, \dots, T$$

Estimating β_k and β_l requires investigating the unknown function $f(\cdot)$ and $\omega(\cdot)$. Following [Wooldridge \(2009\)](#), these functions are specified as:

$$\omega(k_{it}, m_{it}) = \gamma_0 + c(k_{it}, m_{it})\gamma$$

and $f(\cdot)$ can be approximately explained by a polynomial in ω

$$f(\omega) = \rho_0 + \rho_1\omega + \dots + \rho_n\omega^n$$

From where the production function can be rewritten as:

$$y_{it} = \zeta_0 + \beta_k k_{it} + \beta_l l_{it} + c_{it}\gamma + \varepsilon_{it} \quad t = 1, \dots, T \quad (6)$$

and

$$y_{it} = \alpha_0 + \beta_k k_{it} + \beta_l l_{it} + \rho_1(c_{i1}\gamma) + \dots + \rho_n(c_{it-1}\gamma)^n + u_{it} \quad t = 2, \dots, T \quad (7)$$

where $\zeta_0 = \beta_0 + \gamma_0$ and $\alpha_0 = \zeta_0 + \rho_0$.

Following [Wooldridge \(2009\)](#), the GMM is performed to estimate Regressions (6)-(7).² Once β_k, β_l and β_m are estimated, the firm's TFP (in the log) is computed as:

$$\omega_{it} = y_{it} - \beta_k k_{it} - \beta_l l_{it} - \beta_m m_{it} \quad (8)$$

²In Stata, command *prodest* allows the Wooldridge estimation for production function.

Appendix C: Supermodularity/submodularity test

Following [Mohnen and Röller \(2005\)](#) and [Mothe et al. \(2015\)](#), we let $\hat{\gamma}$ be the consistent estimator of γ and $\tilde{\gamma}$ be the estimator closest to γ under the null hypothesis. The Wald test statistic is defined as the minimum of the distance D between $S\tilde{\gamma}$ and $S\hat{\gamma}$. It can be calculated as:

$$\min_{\tilde{\gamma}} (S\tilde{\gamma} - S\hat{\gamma})' [Scov(\tilde{\gamma})S']^{-1} (S\tilde{\gamma} - S\hat{\gamma}), \quad s.t. S\tilde{\gamma} \leq 0 \quad (9)$$

D follows a $\chi^2(df)$, $df = 1$ and $df = 4$. The value of D will be compared with the lower- and upper-bound critical values at the significant level 10% of the number of degrees of freedom, say $df = 1$ (1.642) for ‘no equality restrictions’ and $df = 4$ for ‘four inequality restrictions’ (7.094). We reject the null hypothesis if D is non-negative and more significant than the critical value. The null hypothesis will be accepted if the Wald test value is below the lower bound; and if the value between the lower- and upper bounds is inconclusive.

Appendix D: Specification test

The regression results are presented in [Table A3](#). The first two columns of [Table A3](#) are the simple fixed-effect models without IV and random effect; the IV-FE is notified in column 3. For FE and RE, the test shows that $\chi^2(22) = 629.24$, $p - value < 2.2e - 16 < 0.1$; the null hypothesis H_0 hence is rejected at 1% significant level, and FE is supported to be consistent. For selecting FE and IV-FE, the test shows that $\chi^2(22) = 1.5546$, $p - value = 1 > 0.1$; H_0 could not be rejected at a 10% significant level. Next, selecting FE and Hausman-Taylor estimators shows that $\chi^2(22) = 549.89$, $p - value < 2.2e - 16 < 0.1$, which rejects H_0 and the Hausman-Taylor estimator is preferred. Finally, the best one is the Hausman-Taylor estimator, and its coefficients are employed to conduct complementarity and substitutability tests.

Appendix E: Estimation methodology

TFP estimates

The [Wooldridge \(2009\)](#)’s method to estimate the stochastic TFP is derived based on previous TFP estimation methods of [Olley and Pakes \(1996\)](#); [Levinsohn and Petrin \(2003\)](#); [Akerberg et al. \(2015\)](#). The method is built based on the following production function:

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + \beta_m m_{it} + \omega_{it} + \varepsilon_{it}, \quad (10)$$

where y_{it} , k_{it} , l_{it} are firm i 's log of output, capital stock, and total employees at period t , respectively; m_{it} is a set of intermediate inputs measured by materials cost; ω_{it} is stochastic productivity.

While the previous study suggested a two-stage estimation of Equation (10) by ignoring β_l in the first stage (Akerberg et al., 2015), Wooldridge (2009) argued this two-stage estimation has some disadvantages: (1) they ignore the error term in the first stage, which could reduce the estimation efficiency; (2) the problem of serial correlation is highly likely. Woodridge proposes an alternative method with one-step estimation using the generalized method of moments (GMM).

In the first stage, the stochastic productivity function is denoted as follows:

$$\omega_{it} = \omega(k_{it}, m_{it}), \quad (11)$$

where m_{it} is intermediate material inputs. By assuming that ω_{it} is invariant over time, we have the following condition:

$$E(\varepsilon_{it} \mid l_{it}, k_{it}, m_{it}) = 0, \quad t = 1, \dots, T. \quad (12)$$

Thus, the estimation of Equation (10) can be rewritten as follows:

$$\begin{aligned} E(y_{it} \mid l_{it}, k_{it}, m_{it}) &= \beta_0 + \beta_l l_{it} + \beta_k k_{it} + \omega(k_{it}, m_{it}) \\ &= \beta_l l_{it} + f(k_{it}, m_{it}), \end{aligned}$$

where $f(k_{it}, m_{it}) = \beta_0 + \beta_k k_{it} + \omega(k_{it}, m_{it})$.

Therefore, following the GMM method, estimators β_l and β_k can be estimated by solving these following conditions:

$$\begin{cases} E(\varepsilon_{it} \mid l_{it}, k_{it}, m_{it}, l_{it-1}, k_{it-1}, m_{it-1}, \dots, l_{i1}, k_{i1}, m_{i1}) = 0, & t = 1, \dots, T. \\ E(\omega_{it} \mid \omega_{it-1}, \dots, \omega_{i1}) = E(\omega_{it} \mid \omega_{it-1}), & t = 2, \dots, T. \\ \xi_{it} = \omega_{it} - E(\omega_{it} \mid \omega_{it-1}), & (k_{it} \perp \xi). \end{cases}$$

In the second stage, from the orthogonal condition that $\xi_{it} \perp (k_{it-1}, m_{it-1})$, the sufficient condition can be derived as follows:

$$E(\omega_{it} \mid l_{it}, k_{it}, m_{it}, l_{it-1}, k_{it-1}, m_{it-1}, \dots, l_{i1}, k_{i1}, m_{i1}) = E(\omega_{it} \mid \omega_{it-1}) = f[\omega(k_{it-1}, m_{it-1})].$$

Then, the production function in Equation (10) can be rewritten as follows:

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + f[\omega(k_{it-1}, m_{it-1})] + u_{it}, \quad t = 2, \dots, T,$$

where $u_{it} \equiv \xi_{it} + \varepsilon_{it}$. Then, follow Wooldridge (2009), the orthogonal conditions can be derived as:

$$E(u_{it} \mid k_{it}, l_{it-1}, k_{it-1}, m_{it-1}, \dots, l_{i1}, k_{i1}, m_{i1}) = 0 \quad t = 2, \dots, T \quad (13)$$

Thus, we can apply the GMM to solve the condition 13 to find β_l, β_k and the estimated stochastic productivity. The coefficients of β_k and β_l are presented in Table (5). Detailed methodology is discussed in Appendix B.

Impacts of synergy strategies on TFP

Suppose that TFP is affected by choosing different synergy strategies g , where $g = \{1, 2, \dots, n\}$ represents g combined strategies. Let TFP of firm i at time t choosing strategy g be $TFP(s_{i,g}, \phi_{it})$, where ϕ_{it} is the characteristics of firm i at period t . Thus, a firm i decides to choose a synergy strategy g such that

$$\max_g \Psi_{it}(s_{i,g}, \phi_{it}),$$

where $\Psi_{it} \equiv \ln TFP_{it}$.

In this study, each firm decides to choose four different practices, including “Environmental compliance” (*Environment*), “Product innovation” (*Product*), “Process innovation” (*Process*) and “Having export activities” (*Export*). Synergy strategies, $s_{i,g}$, where $g \in [0, 15]$, are the combinations of these four practices *Environment, Product, Process, Export* (see Table A4). For instance, when $g = 0$, $s_{i,0} = s_{i,0000}$ indicating that firm i chooses non of the four practices, while $s_{i,15} = s_{i,1111}$ when $g = 15$ indicating that firm i chooses all of the four practices. Similarly, $s_{i,1} = s_{i,0001}$ when $g = 1$ meaning that firm i implement only practice *Export*. Thus, there are totally 16 different possible synergy strategies.

The impacts of different synergy strategies on TFP can be written as the following regression function:

$$\Psi_{it} = \sigma_0 + \sum_{g=0}^{15} \gamma_g s_{i,g} + X'_{it}\theta + Z'_{it}\phi + \mu_i + \varepsilon_{it}, \quad (14)$$

where $s_{i,g}$ is the vector of binary variables representing the strategies chosen by firm i ; X'_{it} is a set of time-varying control variables (e.g., abatement cost, firm size); Z'_{it} is a set of time-invariant control variables, including technological sectors and industrial zone; μ_i and ε_{it} are individual and time-specific unobservable effect.

The model fixed effect with instrumental variable (IV-FE) is likely to be inconsistent with estimating Equation (14) because of a possibility of endogeneity on the main variable “*Environment*”. Firms that comply with environmental laws (i.e., obtain an ESC certificate) may be more productive. Although this issue can be solved by examining the effect merely for the group of firms who follow ESC by law, we still believe that there would be omitted variable bias. For instance, the level of pollution each firm emitted was unable to control because it

Table A4: Synergy strategies of environmental compliance (*Environment*), product innovation (*Product*), process innovation (*Process*), and having export activities (*Export*).

Combination (g)	γ_g	$s_{i,g}$	Practices			
			Environment	Product	Process	Export
0	γ_0	$s_{i,0000}$	0	0	0	0
1	γ_1	$s_{i,0001}$	0	0	0	1
2	γ_2	$s_{i,0010}$	0	0	1	0
3	γ_3	$s_{i,0011}$	0	0	1	1
4	γ_4	$s_{i,0100}$	0	1	0	0
5	γ_5	$s_{i,0101}$	0	1	0	1
6	γ_6	$s_{i,0110}$	0	1	1	0
7	γ_7	$s_{i,0111}$	0	1	1	1
8	γ_8	$s_{i,1000}$	1	0	0	0
9	γ_9	$s_{i,1001}$	1	0	0	1
10	γ_{10}	$s_{i,1010}$	1	0	1	0
11	γ_{11}	$s_{i,1011}$	1	0	1	1
12	γ_{12}	$s_{i,1100}$	1	1	0	0
13	γ_{13}	$s_{i,1101}$	1	1	0	1
14	γ_{14}	$s_{i,1110}$	1	1	1	0
15	γ_{15}	$s_{i,1111}$	1	1	1	1

was not mentioned in the survey. The legal basis for following the ESC certificate was vague in what kinds of pollutants need to be decreased. Due to its inability to control for this, it can be certain that a naive OLS estimator of the impacts of environmental compliance on productivity could be biased. Therefore, we proposed “Knowledge about environmental law” (*KEL*) as an instrumental variable (IV) for *Environment*. *KEL* is encoded as a dummy, which equals 1 if the firm’s owner/top manager has either good or average knowledge of environmental law, 0 if they have either poor expertise or are not concerned. The IV is valid for two assumptions: relevance and exclusion restriction conditions. Concerning the relevance, *KEL* is significantly correlated with “*Environment*”, which was checked by the first stage of IV regression on *Environment* (see Table A2). About the exclusion restriction, *KEL* could have only an indirect impact on TFP through “*Environment*”. This approach makes perfect sense since no one can argue that TFP affects *KEL*; otherwise, the latter seems unable to influence TFP.

In addition to IV-FE, we proposed the Hausman-Taylor estimator as an alternative to the IV-FE because of its advantages. The HT estimator allows us to control for time-constant and time-varying variables that could correlate with the individual-specific unobservable effect μ_i .

More precisely, we used X'_{it} as a set of time-varying control variables, such as a log of abatement cost and firm size and Z'_i as a set of time-invariant control variables, such as technological sector and industrial zone. The HT estimator would be more efficient than others if there exist correlations between S_g , X_{it} , Z_{it} and μ_i , $E(\mu_i|S_g, X_{it}, Z_{it}) \neq 0$. The Hausman test is used to compare efficient and consistent performance for each of these four estimators to select the best estimator.

Supermodularity and submodularity test

This section aims to examine the relationship between different practices (i.e., environmental compliance, product innovation, process innovation, and export activities). The existing literature has suggested that because of the correlation between indicators comprising the synergies, the statistical significance of synergies coefficients could not be concluded separately (Mohnen and Röller, 2005; Mothe et al., 2015). Thus, the supermodularity and submodularity tests are useful to analyze the relationship between different practices comprising the synergy strategies using their linear inequality restriction and joint distributions (Milgrom and Roberts, 1990, 1995; Mohnen and Röller, 2005; Mothe et al., 2015; Van Leeuwen and Mohnen, 2017).

Following the theory of supermodularity and submodularity, practices a and b are complementary if the following supermodular condition holds.

$$\gamma(10cd) + \gamma(01cd) \leq \gamma(00cd) + \gamma(11cd),$$

where $c, d = \{0, 1\}$; $\gamma(10cd) + \gamma(01cd)$ is a substituted impact of practice a and practice b on TFP, while $\gamma(00cd) + \gamma(11cd)$ represents their complementary impact on TFP. Thus, the complementary between *Environment* and *Product* could be written as follows:

$$\gamma_{4+m} + \gamma_{8+m} \leq \gamma_{0+m} + \gamma_{12+m}, \quad m = \{0, 1, 2, 3\}. \quad (15)$$

The complementary between *Environment* and *Process* is validated if:

$$\gamma_{2+m} + \gamma_{8+m} \leq \gamma_{0+m} + \gamma_{10+m}, \quad m = \{0, 1, 4, 5\}. \quad (16)$$

Similarly, we can derive the complementary between other practices (*Environment* and *Export*; *Product* and *Process*; *Product* and *Export*; *Process* and *Export*) as follows:

$$\gamma_{1+m} + \gamma_{8+m} \leq \gamma_{0+m} + \gamma_{9+m}, \quad m = \{0, 2, 4, 6\}. \quad (17)$$

$$\gamma_{2+m} + \gamma_{4+m} \leq \gamma_{0+m} + \gamma_{6+m}, \quad m = \{0, 1, 8, 9\}. \quad (18)$$

$$\gamma_{1+m} + \gamma_{4+m} \leq \gamma_{0+m} + \gamma_{5+m}, \quad m = \{0, 2, 8, 10\}. \quad (19)$$

$$\gamma_{1+m} + \gamma_{2+m} \leq \gamma_{0+m} + \gamma_{3+m}, \quad m = \{0, 4, 8, 12\}. \quad (20)$$

Let us denote h_m as the complementary condition between *Environment* and *Product* from the Inequality equation (15). We have

$$h_m = -\gamma_{0+m} + \gamma_{4+m} + \gamma_{8+m} - \gamma_{12+m}, \quad m = \{0, 1, 2, 3\}. \quad (21)$$

Thus, the hypothesis test for complementarity between *Environment* and *Product* is written as follows:

Null hypothesis: $H_0: h_0 < 0, h_1 < 0, h_2 < 0, h_3 < 0.$

Alternative hypothesis: $H_1: h_0 \geq 0$ or $h_1 \geq 0$ or $h_2 \geq 0$ or $h_3 \geq 0.$

Let $\hat{\gamma}$ be the consistent estimator of γ and $\tilde{\gamma}$ be the estimator closest to γ under the null hypothesis. According to the Kodde-Palm test (distance test) (Kodde and Palm, 1986), the test statistic for the hypothesis mentioned above is defined as the minimum distance between $S\tilde{\gamma}$ and $S\hat{\gamma}$ (Mohnen and Röller, 2005; Mothe et al., 2015).

$$\min_{\tilde{\gamma}} (S\tilde{\gamma} - S\hat{\gamma})' [S * cov(\tilde{\gamma}) S']^{-1} (S\tilde{\gamma} - S\hat{\gamma}), \quad s.t. S\tilde{\gamma} \leq 0. \quad (22)$$

Assessing the complementarity of four environmental and economic practices requires joint tests of two inequality constraints for each pairwise comparison. Accordingly, the null hypothesis H_0 is rejected if the test statistic is higher than the upper bound critical value; H_0 is accepted if the test statistic is lower than the lower bound critical value defined by Kodde and Palm (1986); otherwise, the test is inclusive if the test statistic is between the upper and lower bounds defined by Kodde and Palm (1986).

Appendix F: Summary literature on DANIDA database

Table A5: Summary literature on DANIDA database.

Author	Year	Journal	Description	Dependent variable	Explanatory variable
(1)	(2)	(3)	(4)	(5)	(6)
Ngoc et al. (2023)	2023	Fulbright Review of Economics and Policy	Authors investigated Outsourcing to SMEs in a developing country can significantly increase its TFP.	Total factor productivity	Outsourcing activities
Vu and Tran (2021)	2021	Finance Research Letters	Study indicated that access to financial support improves technological progress and growth in firm scale but has a negative effect on improvement in technical efficiency.	Productivity, Innovation	Government financial support
Efobi et al. (2022)	2021	Small Business Economics	Authors suggested practicality of enterprises improve enterprises' performance.	Enterprises' performance	Practicality
Nam and Bao Tram (2021)	2021	Economics of Innovation and New Technology	Study assesses that persistence is observed for moderately complex innovation in weak business environment.	Innovation	Business environment measured by Provincial Competitiveness Index
Tsai et al. (2021)	2021	Sustainability	Authors suggested that embracing more environmental-related certificates and technology increases productivity.	Productivity	Environmental certificates
Nam and Bao Tram (2021)	2021	Economics of Innovation and New Technology	Policies to improve business environment enhance innovation policies and, thus, promote innovation of the SMEs that are inexperienced in carrying out such innovation.	Export	Innovation
Tran and Pham (2020)	2020	Management Science Letters	The role of institutional environment on CEP, political connections had a negative effect on CEP in the context of Vietnam.	Corporates' environmental performance	CEOs' characteristics
Archer et al. (2020)	2020	Applied Economics	Credit constraints may not always impede innovation.	Innovation	Credit constraints

Nguyen et al. (2020)	2020	Sustainability	Innovation factors significantly impact on credit accessibility.	Credit accessibility	Innovation
Giang et al. (2019)	2019	Sustainability	Financial accessibility could directly enhance firm productivity.	Productivity	Financial accessibility
Nguyen and Le (2019)	2019	Asia Pacific Business Review	Social networks contribute positively to the export propensity of SMEs.	Export	Social networks
Calza et al. (2019)	2019	Economics of Innovation and New Technology	Innovation related to technological capabilities, international standards are conducive to higher productivity.	Productivity	International standards
Giang et al. (2018)	2018	Sustainability	The investment climate were harmful to firm productivity.	Productivity	Investment climate includes infrastructure, labor skills, regulatory governance and institutions, and access to finance
Nguyen et al. (2018)	2018	Journal of Asian Business and Economic Studies	There is no impact of ownership concentration on innovation, but it has a positive impact on sales growth; But, innovation positively affects firm performance.	Performance	Innovation
Trifković (2017)	2017	World Development	Certified firms pay higher wages and offer formal contracts.	Labor productivity	International standards
Trifković (2017)	2017	World Development	Certified firms pay higher wages on average, implying that the adoption of standards could boost labor productivity.	Productivity	Formality
Dung et al. (2017)	2017	Journal of Developmental Entrepreneurship	Formality of the employment contract significantly and positively influences some aspects of the firm's innovation.	Innovation	Formality
Nguyen et al. (2016)	2016	Crime, Law and Social Change	Informal payments by Vietnamese firms encourage overall innovation.	Innovation	Corruption (Informal payment)

Nguyen-Huu (2016)	2016	Economics Bulletin	Firms' TFP convergence is rather related to their characteristics than their geographic location and/or industrial characteristics.	TFP convergence	Geographic and/or industrial characteristics	location
Newman et al. (2015)	2015	European Economic Review	Productivity gains through forward linkages for domestic firms that receive inputs from foreign-owned firms.	Productivity	FDI	
Nam (2014)	2014	Journal of Economics and Development	Human and social capital of SMEs is a key to innovation in product, production process, marketing, and performance of SMEs in Vietnam.	Innovation, Performance	Human and social capital	
Newman et al. (2014)	2014	UNU-WIDER Research Paper	Investment in technology and innovation play important roles in determining enterprise productivity levels.	Productivity performance	Technology, investment and ownership structure	
Vu et al. (2013)	2015	Economics Bulletin	Export mode exhibit a higher probability of survival.	Survival	Export	
Rand and Torm (2012)	2012	World Development	Firms moving into formality promotes the productivity and longer-term stability of the business.	Profit	Formality	
Anh et al. (2011)	2011	Globalization and Innovation in East Asia	Innovation is strongly influenced by trade liberalization.	Innovation	Foreign Competition	
Tran et al. (2008)	2008	Asian Economic Journal	Positive effect of direct government financial and non-financial assistance to businesses associated with improvement in technical efficiency.	Technical efficiency	Direct government financial and non-financial assistance to businesses	
Nguyen et al. (2008)	2008	The European Journal of Development Research	Innovations are important determinants of exports by Vietnamese SMEs	Export	Innovation	