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The Impact Of Trade Liberalization On Industrial Pollution: Empirical Evidence From Vietnam

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This study assesses the impact of trade liberalization on the environment in Vietnam. In particular it looks at the link between the amount of pollution produced by the country's manufacturing industries and the degree to which this is affected by trade liberalization policies.

The study was carried out by Pham Thai Hung, Bui Anh Tuan and Nguyen The Chinh, from Vietnam's National Economics University. It finds that trade liberalization in the country exacerbates industrial pollution at both the firm and industry level. This trade-off is worrying as Vietnam has recently become a WTO member and further trade liberalization commitments are now in the pipeline.

In light of their findings, the researchers recommend that the environmental impact of any future trade reforms should be carefully considered and that steps should be taken to mitigate any potential negative effects such reforms might have.

They suggest that polluting industries should be given priority in any clean-up programme. They highlight key steps which can be taken to help reduce pollution, including the strict enforcement of environmental regulations support to promoting information technology application and technology advancement in the manufacturing sector.

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THE IMPACT OF TRADE LIBERALIZATION ON INDUSTRIAL POLLUTION: EMPIRICAL EVIDENCE FROM VIETNAM

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EXECUTIVE SUMMARY

Although trade reform in Vietnam in recent years has been commonly recognized as a success story, its potential impact on the environment has not been subject to empirical investigation. Using data from the Vietnam Enterprise Survey (VES) of 2002 and the World Bank's Industrial Pollution Projection System (IPPS), this study conducted a partial equilibrium econometric analysis to examine whether trade liberalization had exacerbated pollution in Vietnam's manufacturing sector.

Based on the water pollution, air pollution, and toxic pollution projected data using the 2002 VES and the IPPS pollution coefficients, this study found that industrial pollution was heavily concentrated in the Southeast and the Red River Delta in the north. Paper products, chemicals, fertilizers, iron and steel, textiles and garments, and food and beverages were among the top polluting industries. The central-level state-owned enterprises (SOEs) were found to be major contributors to industrial pollution. Our regression analysis revealed that trade liberalization has exacerbated industrial pollution at both the firm and industry levels. This trade effect, however, did not prove to be very sensitive to certain proxies of trade exposure. The trade-off between trade liberalization and industrial pollution is worrying given that Vietnam has recently become a World Trade Organization (WTO) member and further trade liberalization measures are imminent.

However, this does not necessary imply a call for trade restrictions. Instead, our study suggests that more explicit awareness of the trade-off between trade liberalization and pollution is necessary, particularly in pursuing the recently mandated Strategic Environmental Assessments (SEAs) at the sectoral level. Further trade reforms should be fully considered in a broad context and potential negative effects on the environment need to be addressed by appropriate policy measures. Given that the current resources for environmental protection are limited, it is desirable to give priority to the top polluting industries. Enforcing environmental regulations and ensuring that information technology applications are environmentally friendly are particularly important. Speeding up the SOE reform agenda is also called for, especially at the central level.

1.0 INTRODUCTION

Along with the Vietnam's impressive growth over the past 15 years, the volume of waste from industrial activities and households has increased rapidly. Of the total of 15 million tonnes of waste produced each year, industry generates over 2.6 million tonnes, which is equal to 17%, making it the second largest source. The liberalization of trade and investment has been crucial for the country's recent economic growth, however, the trade-induced industrial clusters that have emerged are also the main sources of industrial pollution (World Bank, MoNRE and CIDA 2004). During the period 1990-2005, there was a dramatic shift in the export pattern towards a dominance of the manufacturing sector (i.e., from 54% to approximately 74%). In addition, the proportion of developed countries in the structure of the export market has increased sharply from a mere 22% to 70%. Given that Vietnam has relatively weaker environmental regulations than its main trading partners, this has raised concerns as to whether the expansion of trade may exacerbate environmental degradation. Furthermore, the fact that more than 60% of foreign direct investment has been concentrated on manufacturing activities also raises the question of potential environmental consequences. In this context, Vietnam might not be an exception in terms of the increasing recognition of the negative impacts of trade liberalisation, particularly on environmental and natural resources, in developing countries and transition economies.

The empirical evidence on industrial pollution and the potential impacts of trade liberalization on the environment in Vietnam is rather limited. The Vietnam Environment Monitor reports during the period 2003-2005 focused on the degradation of natural resources and biodiversity[1]. Meanwhile, a review of a dozen recent papers on industrial pollution in Vietnam produced an incomplete picture of the situation as most of the studies used data collected from small-scale surveys or 'case studies' (see Palladino 2001; Le and Nguyen 2004; Pham and Vo 2005; Nguyen 2005; Vu 2005). Perhaps the most significant contribution in understanding the impacts of the *Doi moi* (renovation) process on industrial pollution can be arguably linked to Mani and Jha (2005) who used industry-level data to examine the composition of Vietnamese production and exports between 1997 and 2002. The study reported that "manufacturing output has been significantly higher from water pollution intensive sectors compared to the less pollution intensive sectors …. exports in Vietnam have increased significantly from the toxic pollution intensive sectors and foreign direct investments have been higher in the toxic pollution intensive sectors" (p.18). They did not provide a direct link, however, between trade liberalization and the environment.

The lack of statistical data on industrial pollution in Vietnam is probably a good explanation for the limited understanding of the trade effect on industrial pollution in the country. The General Statistics Office (GSO) has no reported data on the environment in its system while the environmental database developed and monitored by the National Environment Agency (NEA), a useful source of statistical data on natural resources, provides few indicators on industrial pollution. In this context, this research aimed to empirically examine the determinants of industrial pollution. The focus was on the *direct* impact of trade liberalization on the environment, while the environmental impacts of the *indirect* effects of trade liberalization such as increased income and growth were not measured (for an explanation of the indirect impact, see Dean 2002).

The structure of this paper is as follows. The next section provides a literature review on the trade-environment debate and the potential implications of Vietnam's trade reform on industrial pollution. Section 3 describes the methodology and data sources used in this research. The empirical results are then analyzed in Section 4 with a focus on trade-environment linkages. Finally, conclusions, policy implications and recommendations are provided in Section 5.

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[1] These reports are considered as the most comprehensive on current environmental issues in Vietnam. They are the products of a joint effort between the Vietnamese government (through the Ministry of Natural Resources and Environment – MoNRE) and international donors led by the World Bank together with DANIDA, CIDA, and Sida.

2.0 TRADE AND ENVIRONMENT IN DEVELOPING COUNTRIES

2.1 Trade and Environment: A Literature Review

The early theoretical development of the trade-environment debate can be linked to, inter alia, Pethig (1976), Siebert (1977), and McGuire (1982). Pethig (1976), using a Ricardian model with labour and emissions as inputs, argued that a country would specialize in environment-intensive goods if their environmental regulations were less restrictive than those in other countries. Siebert (1977) expanded Pethig's analysis and stressed that environmental policy could be friendly to the environment at the expense of reducing the output of the good that required the intensive use of natural resources for its production. A similar argument is found in the Heckscher-Ohlin framework by McGuire (1982), who added the environment, which is subject to a quantitative restriction, as an additional factor of production. As cited in Anriquez (2002, p.2), if the restriction is too restrictive, "it can revert a comparative advantage the country may enjoy in the good that (intensively) uses the environment".

More recent literature on trade and environment emphasizes the role of property rights. Chichilnisky (1994), adopting the neo-classical Heckscher-Ohlin model, argued that developing countries, which are usually located in the South and suffering from severe property rights failures, extract more from the environment than is optimal, for any given price of the environmental good, in comparison to developed countries in the North. In this setting, the South has the standard endowment-type comparative advantage in environment-intensive goods. However, as it does not internalize this, it is not a 'real' comparative advantage. Consequently, trade liberalization in developing countries would exacerbate environmental problems by over-harvesting the environment while developed countries would 'gain' from trade liberalization in the absence of property rights failures.

Brander and Taylor (1997a) expanded the Chichilnisky's (1994) North-South framework by introducing renewable resources into the model. Renewable resources are said to have a regenerative capacity that is commonly illustrated by an inverted-U shaped function. When the stock of renewable resources is high, trade liberalization would not put the resources in danger, and thus the South could still benefit from increasing the export of resource-intensive goods. However, if the stock of renewable resources falls below optimal levels, meaning a failure of the property rights regime, trade liberalization would result in the same negative scenario for developing countries as predicted by Chichilnisky (1994). In the context of the North-South trade, trade liberalization together with effectively enforced environmental restrictions in the North would move pollution-intensive industries down to the South (Copeland and Taylor 1994). This is often cited as 'industry flight' or 'industry migration' to so-called 'pollution havens' in the South (Ederington, Levinson and Minier 2004).

While the North-South model assumes that developed countries are free of property rights failures while developing countries suffer from such failures, the South-South model (see Brander and Taylor 1997b for a review) analyzes the trade-environmental linkages among developing countries in the presence of open access externalities[2]. Brander and Taylor (1997b) considered two countries with different endowments of labour and natural resources. The country with more natural resources relative to labour, exported its resource goods and thus lost environmentally from the process (as it did not internalize the open access externality), whereas the importing country gained. In a similar inference, Karp, Sandeep and Jinhua (2001) suggested that the same result could occur with differences in the levels of the environmental externalities and environmental stock, rather than from differences in natural resource endowments.

Grossman and Krueger (1993) popularized a useful approach in understanding trade-environment linkages by decomposing the consequences of trade in terms of scale, composition, and technical effects. The scale effect refers to changes in pollution caused by output expansion assuming the nature of economic activity remains unchanged (i.e., all sectors expand in equal proportions and the level of productivity remains unchanged). However, it is reasonable to expect that trade liberalization would cause an expansion of sectors with comparative advantages and a decline of those with comparative disadvantages. As factors are reallocated according to trade-induced changes in relative prices, the resulting change in the output structure will lead to changes in pollution levels. This is called the composition effect. Finally, opening up domestic markets to trade and foreign investment makes it more likely that firms will change their production technologies, leading to new environmental consequences. Using this framework, Grossman and Krueger (1993) show an inverted-U shape, which is the so-called Environmental Kuznet Curve, to illustrate the dynamics of pollution. It implies that as income grows (as a response to trade liberalization), pollution will increase until a certain level before diminishing.

The preceding discussion on the theoretical aspects of trade-environment linkages suggests that there may be 'losers' and 'winners', environmentally, from trade liberalization, at least in the short or medium term. Whether a country is a loser or winner from trade liberalization depends on how well endowed it is in terms of natural resources; the existence and more importantly, the enforcement of environmental regulations; and the time of adjustment of economic activities, policies, and consumption behaviour to trade liberalization . This has been the subject of a growing number of empirical studies which aim at quantifying the impact of trade on the environment. Robinson (1988) showed that the pollution content of imported goods rose faster than the pollution content of exported goods in the US between 1973 and 1982, meaning a shift in US trade towards importing relatively more pollution-intensive goods. Low and Yeats (1992) compared the trade flows from developing countries in the periods 1967–1968 and 1987–1988 and reported that dirty industries accounted for a growing share of exports in some developing countries, which was then said to be evidence of 'industry flight' into these countries. In a similar study, Mani and Wheeler (1999) also reported supporting evidence on the negative impacts of trade liberalization on the environment in Third World countries.

In contrast to empirical evidence that tended to be environmentally opposed to trade liberalization, other studies have unambiguously reported that trade liberalization

[2] Open access externality in environmental economics refers to the situation in which property rights are insufficient or unenforceable to prevent general use (i.e., open access) of natural resources, leading to destruction/diminishment/damage of the resources under consideration.

has little to do with environmental degradation in developing countries. Results from Tobey (1990), who used a Heckscher-Ohlin-Vanek model, indicated that environmental control was not a valid variable in explaining the patterns of trade. Meanwhile, Grossman and Krueger (1993) investigated data on Mexican exports to the US and confirmed that environmental policy had no effect over trade flow. Wheeler (2001) supplied further evidence that strongly contradicted the hypothesis of dirty industry migration. He showed that the countries that have received the greatest share of the world's overall foreign direct investment, including Brazil, Mexico and China, have actually shown a reduction in the levels of urban pollution.

As neither theory nor empirical study has been able to provide a conclusive answer to the trade-environment relationship, whether there is a trade-off between them is largely an empirical question to be answered in a specific context. This study deals with this question in the context of Vietnam's manufacturing sector.

2.2 Vietnam's Trade Reforms and Potential Implications for the Environment

With Vietnam's commitments to the WTO, its economy has become increasingly open to international market forces over the past two decades (see Appendix 1 for major trade reforms). Figure 1 shows an impressive growth of exports and imports from 1990–2004 during which the structure of Vietnam's export profile shifted significantly. The export growth in the first half of the 1990s was largely led by agricultural products, which accounted for an average of 45% (Table 1). From 1997–2004, light manufacturing exports surpassed agricultural export turnover due to the rapid growth of garment, footwear, and seafood industries, and the collapse of world prices for Vietnam's major agricultural exports (World Bank 2006b). Along with the high export growth, imports expanded by an average of 21% per year in the period 1990–2004. The import structure reflects the demand for raw materials, fuel, equipment, and machinery for domestic production. These products dominated import transactions, accounting for an average of 90% of the total imports (Table 1).

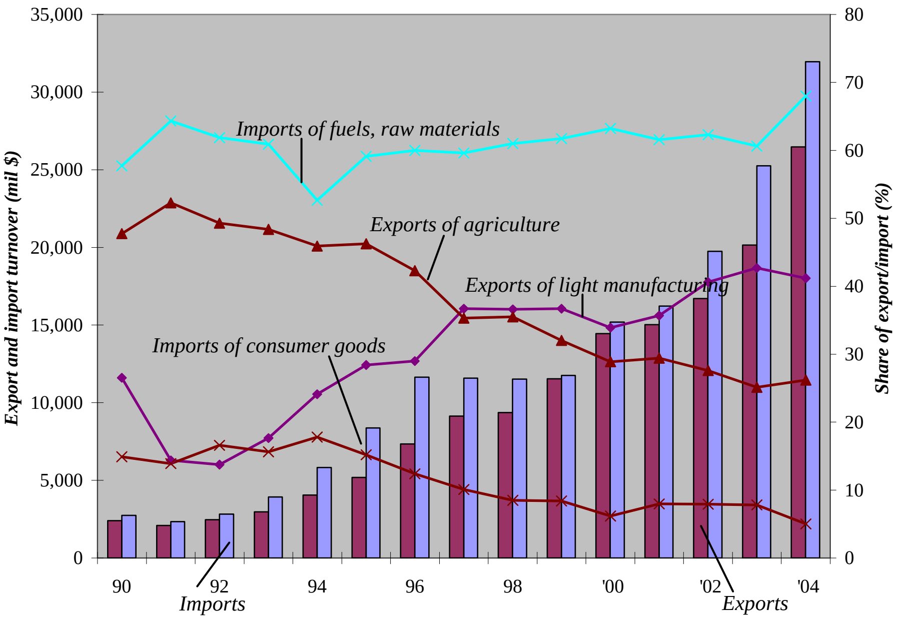

Figure 1. Export and import: turnover and structures (1990-2004)

Source: compiled from GSO 1996, 2001 and 2006

Notes:

(1) Export values and shares refer to total exports including crude oil.

(2) Light manufacturing consists of garments, footwear, seafood (processed), handicrafts and other light manufacturing products.

Table 1. International trade and investment flows (1990-2004)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
International Trade															
Export (US$ mil.)	2,404	2,087	2,475	2,985	4,054	5,198	7,337	9,145	9,365	11,540	14,449	15,029	16,706	20,149	26,485
Import (US$ mil.)	2,752	2,338	2,817	3,924	5,827	8,381	11,644	11,592	11,527	11,742	15,200	16,218	19,746	25,256	31,969
Trade deficit															
− Trade deficit as % of GDP	-5.95	-4.11	0.39	-7.44	-12.54	-13.97	-19.09	-9.23	-7.99	-0.29	-2.96	-3.62	-8.66	-13.03	-12.06
− Trade deficit as % of export	-14.49	-12.03	-13.82	-31.46	-43.73	-61.24	-58.70	-26.76	-23.09	-1.75	-5.20	-7.91	-18.20	-25.35	-20.71
Exports by sector (%)															
− Heavy industries and mining	25.73	33.37	36.98	33.97	30.00	25.28	28.70	28.00	27.90	31.30	37.20	34.90	31.80	32.20	32.60
− Light industries	26.52	14.38	13.76	17.65	24.09	28.40	29.00	36.70	36.60	36.70	33.90	35.70	40.60	42.70	41.20
− Agriculture, Forestry, Aquaculture	47.75	52.25	49.26	48.38	45.90	46.27	42.30	35.30	35.50	32.00	28.90	29.40	27.60	25.10	26.20
Imports by sector (%)															
− Machinery and equipment	27.36	21.78	21.54	23.50	29.54	25.71	27.60	30.30	30.60	29.90	30.58	30.52	29.80	31.60	27.00
− Fuel, and raw materials	57.74	64.31	61.89	60.88	52.66	59.11	60.00	59.60	61.00	61.70	63.23	61.56	62.30	60.60	68.00
− Consumer goods	14.90	13.91	16.57	15.62	17.80	15.18	12.40	10.10	8.50	8.40	6.19	7.94	7.90	7.80	5.00
Foreign Direct Investment															
Number of projects [a]	108	151	197	274	367	408	387	358	285	311	389	550	802	748	723
Total capital committed (US$ mil.)	735	1,292	2,209	3,347	4,535	7,696	9,735	6,055	4,877	2,264	2,696	3,230	2,963	3,146	4,222
− % of foreign share	81.50	77.69	82.77	79.98	76.28	76.94	78.63	76.52	72.47	86.58	84.45	96.00	91.72	93.84	89.74
Actual capital implemented (US$ mil.)	n.a.	329	575	1,018	2,041	2,556	2,714	3,115	2,367	2,335	2,414	2,451	2,591	2,650	2,852
− % of total commitment	n.a.	25.46	26.03	30.40	45.00	33.21	27.88	51.44	48.54	103.12	89.53	75.87	87.45	84.25	67.56
Official Development Assistance (ODA)															
Disbursement (US$ mil.)[b]	n.a.	n.a.	n.a.	n.a.	n.a.	189	336	550	796	970	1,361	958	1,073	1,258	1,394

Source: compiled from GSO 1996, 2001, & 2006 (the GSO data on FDI is based on that of MPI); and IMF (2002, 2006) for ODA disbursement data

Notes:

(1) [a] These figures represent the number of new projects licensed each year and do not take into account ended or failed projects.

(2) [b] The IMF does not provide data on ODA disbursements for the years 1990–1994. For these years, IMF (1998) inserted reports on the disbursement of medium and long-term loans, but did not distinguish between ODA and other commercial loans sources.

In terms of trade direction, Vietnam has greatly diversified its export and import markets compared to the early 1990s (Figures 2a and 2b). The collapse of traditional markets (i.e., the former Soviet Union and other socialist countries) has been ‘compensated’ by the emergence of countries from East Asia and the Association of Southeast Asian Nations (ASEAN) as major trading partners. As at 2004, Japan, South Korea, China, and ASEAN countries accounted for more than 60% of the total imports and more than half of Vietnam’s exports. The trade dependence on these countries is one of the main reasons for the cognation effect of the 1997-98 financial regional crisis[3]. At the same time, the European Union (EU) and North America (USA and Canada) became growing export markets, mainly for garments, footwear, and seafood products. Although the EU and North America accounted for less than 20% of Vietnam’s total exports, and 12% of its imports on average during the period 1990–2004, these markets bought 40% of the total exports in 2004 and have been identified as the main target markets in Vietnam’s Export and Import Strategy for 2001-2010 (MoT 2000).

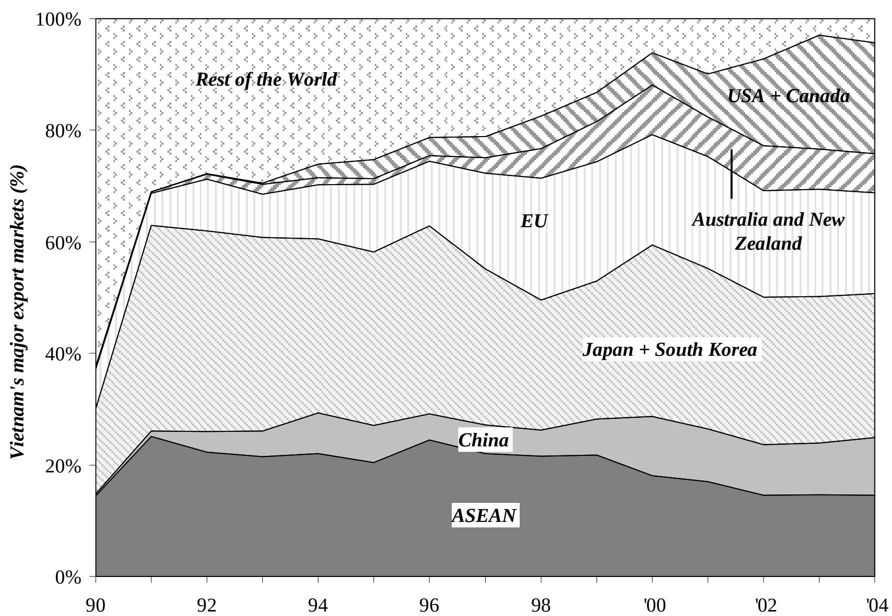

Figure 2a. Vietnam’s direction of trade (Exports, 1990-2004)

Source: compiled from GSO 1996, 2001 and 2006

[3] The regional 1997-98 financial turmoil first started in Thailand and Indonesia with large devaluations of the exchange rates, followed by massive capital outflows. This financial crisis quickly spilled over to neighbouring countries such as Malaysia and the Philippines. At that time, although Vietnam had not yet liberalized its capital account and was hence spared the financial crisis, the cognation effect was felt in terms of decline in exports and foreign investment.

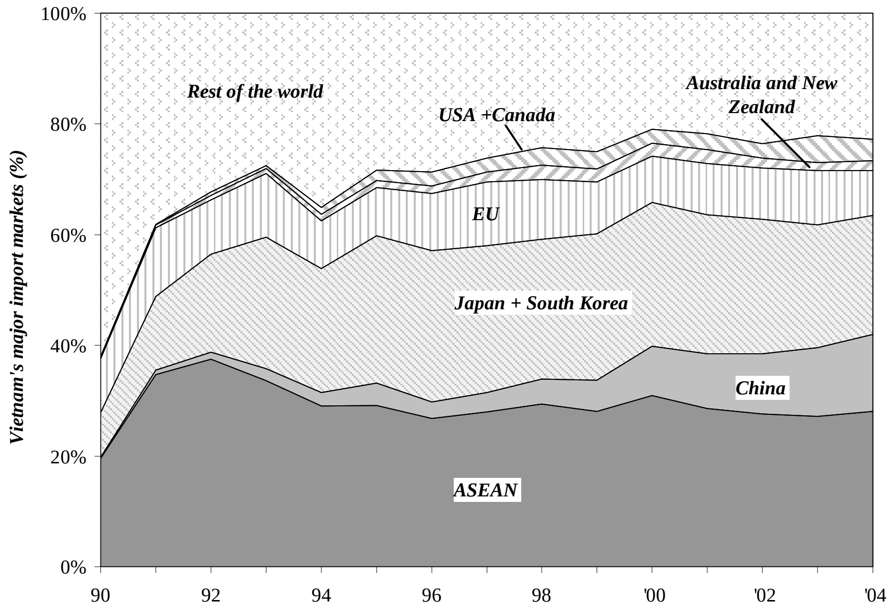

Figure 2b. Vietnam's direction of trade (Imports, 1990-2004)

Source: compiled from GSO 1996, 2001 and 2006

Foreign direct investment (FDI) became a major source of funds for Vietnam during the *Doi moi* (which started in 1986 and is ongoing). Of the total investment of 25.4% of the Gross Domestic Product (GDP) over the past decade, FDI contributed more than one fifth, almost equivalent to a share of nearly six per cent from the state budget (i.e., the total budget for public spending). Given this, the FDI sector's share in total industrial output increased from 25% to 41% between 1995 and 2004. The FDI sector was also the main exporter with its share in total exports rising from below 5% in 1995 to 55% in 2004 (MUTRAP 2002). Table 2 shows that Vietnam depends largely on East Asia, Singapore, and the EU as the main sources of FDI. The top five countries/territories investing in Vietnam are the EU, Singapore, Taiwan, Japan, and South Korea; these accounted for around 64% of the total number of FDI projects and 63% of the total invested capital, both implemented and committed, during the period 1990–2004. In terms of sectoral distribution, the manufacturing sector was the recipient of 65% of the total number of projects and 50% of actual disbursements.

Table 2. Vietnam's FDI distribution—by country of origin, activity and region (1988-2006)

	Number of projects		**Total capital commitment**	
	Number	**%**	**US$ mil.**	**%**
Total investment / projects	7,279	100	66,244	100
By country of origin				
− EU	698	9.59	10,459	15.79
− Singapore	484	6.65	9,328	14.08
− Taiwan	1,615	22.19	8,657	13.07
− Japan	684	9.4	6,907	10.43
− South Korea	1,185	16.28	6,145	9.28
− China (excluding Hong Kong)	951	13.06	5,548	8.38
− Hong Kong	520	7.14	4,707	7.11
− Malaysia, Indonesia, Thailand	417	5.73	3,692	5.57
− United States	319	4.38	2,305	3.48
− Russian Fed.	90	1.24	1,840	2.78
− Australia	161	2.21	1,514	2.29
− Others	675	9.27	9,850	14.87
By activity				
− Agriculture, forestry, fishery	638	8.76	3,685	5.56
− Mining and quarrying	95	1.31	3,336	5.04
− Manufacturing	4,699	64.56	33,192	50.11
− Construction	141	1.94	5,173	7.81
− Hotels and restaurants	233	3.20	5,154	7.78
− Transport and communications	218	2.99	4,664	7.04
− Real estate, business renting activities	872	11.98	6,258	9.45
− Other activities	383	5.26	4,783	7.22
By region				
− Red River Delta	1474	20.25	16,969	25.62
− Northeast	326	4.48	2,140	3.23
− Northwest	27	0.37	105	0.16
− North Central Coast	112	1.54	1,428	2.16
− South Central Coast	318	4.37	3,762	5.68
− Central Highlands	106	1.46	1,025	1.55
− Southeast	4571	62.80	35,941	54.25
− Mekong River Delta	296	4.07	1,978	2.99
− Oil and gas	49	0.67	2,898	4.37

Source: compiled from GSO 1996, 2001, and 2006 for country of origin; and from MPI data in Document No. 2338/BKH-DTNN dated April 06, 2006, for activities (NB: 'oil and gas', according to the GSO statistics, are not categorized under any geographical region)

The structural changes in the Vietnam's trade pattern and direction are likely to have important implications for the environment. Given that Vietnam has exploited its major comparative advantage in labour-intensive and natural resource-intensive exports to its major trading partners, which have generally stronger environmental regulations, its impressive expansion of trade may have negative effects on its environment as predicted by literature. There is also concern that as Vietnam continues with its past rate of rapid growth, it may end up specializing in pollution-intensive industries (Mani and Jha 2005), which will be 'costly' for the environment.

In addition, the FDI flows should also be looked at critically. As most of the FDI projects have been financed by investors from the more advanced countries and concentrated on manufacturing activities, it raises the question of whether this might represent 'industrial flight' where developing countries become 'pollution havens' as suggested by literature (see Ederington, Levinson and Minier 2004 for a review). All these concerns are subject to empirical examination in this study.

3.0 METHODOLOGY

3.1 Modelling the Impact of Trade Liberalization on Pollution

Past empirical studies on the impacts of trade liberalization were carried out using different data sources at the macro level, industry level and most recently, plant level. The main pitfall of the macro-level approach is that macro data on trade exposure cannot capture the differences in the patterns of industrial growth between different industries. This becomes serious when applied to industries with a dispersed protection structure (a structure of trade protection with a very high deviation). In addition, applying this approach raises the question of how to develop an appropriate trade exposure variable at the macro level. On the other hand, the industry-level approach examines the impact of trade liberalization on a single pollution measure for each industry. Although using industry-level data is more specific than using macro data, this approach however ignores cross-firm heterogeneity, which is increasingly important in the new theory of trade[4]. In fact, great heterogeneity across firms has been widely observed in developing countries (Bernard and Jensen 1999; Fernandez 2003). In view of this, this study examined the effects of trade liberalization on industrial pollution at both firm and industry levels.

Following the general form of the pollution abatement cost function suggested in Hettige et al. (1996), the pollution load of individual firm *i* can be expressed as

$$\boldsymbol{p}_i = \beta_o + \boldsymbol{x}_i'\beta_1 + \boldsymbol{t}'\beta_2 + \boldsymbol{d}'\beta_3 + u_i \qquad \text{(Equation 1)}$$

[4] The "new theory of trade" includes models of international trade developed since the late 1970s that incorporate 'new' aspects of international trade, including imperfect competition, increasing returns to scale, and product differentiation in both general equilibrium and partial equilibrium models of trade and trade policies. Many trade economists have contributed to this new trade theory, the most prominent being Paul R. Krugman, who started with "Increasing Returns, Monopolistic Competition, and International Trade" (Krugman 1979).

where $\boldsymbol{p}_i$ is the pollution level (either air, water, land, or total pollution levels) at firm i; $\boldsymbol{x}_i$ is a vector of inputs and other plant-level characteristics; $\boldsymbol{t}$ is the trade openness proxy of the sector in which the firm is operating; $\boldsymbol{d}$ is the set of industry dummies; βs are vectors of coefficients of appropriate parameters; and u_i is the stochastic error term.

This specification has a number of advantages over those applied in Ederington, Levinson and Minier (2004) and Mani and Jha (2005), where pollution is included as a regressor in pollution-augmented production functions. Firstly, Equation (1) hypothesizes a direct link between trade and industrial pollution. Secondly, there is literature that suggests a simultaneity bias caused by serial correlation between the disturbance term in the production function and input choices (see Bernard and Jensen 1999; Levinsohn and Petrin 2000). In other words, having inputs (namely, labour and capital) and pollution as regressors in the production function introduces simultaneity bias and thus results in biased estimates. This limitation, however, does not arise in our case.

Empirical literature on trade and the environment usually distinguishes between 'dirty' and 'clean' industries. This dichotomous distinction has been used in a number of studies to either differentiate between the 'dirty' and 'clean' sub-samples or simply incorporate dummies for dirty and clean industries in the model (for instance, as done by Mani and Jha 2005). In fact, Mani and Wheeler (1999) discuss different methods to identify 'dirty' sectors in their research on 'pollution havens'. However, separating firms according to whether they are in dirty or clean sectors would ignore firm heterogeneity within the same sector. Given this, we did not distinguish between 'dirty' and 'clean' firms in our firm-level analysis, but we took it into account when analyzing the impact of trade liberalization on pollution at the industry level, which was the second econometric strategy of this research.

While the above plant-level analysis allowed firm heterogeneity to be factored in, modelling the impact of trade on pollution at the industry level was also appealing as it could provide insights into the trade-environment linkage at a more aggregated level. This study adopted the method popularized by Krueger and Summers (1988), which was later reinforced by Haisken-DeNew and Schmidt (1997), to estimate inter-industry pollution differentials. This method has been widely applied in trade-wage studies (see Antanasio, Goldberg and Pavcnik 2003 for a review). Applying this approach in our context essentially involved obtaining the pollution deviation level of each industry relative to the national weighted average level, and modelling these differentials against a sectoral trade exposure measure and a number of industry-level characteristics. This framework is outlined below and was based on that used by Haisken-DeNew and Schmidt (1997).

Starting from the firm level, the pollution equation (Equation 1) was reduced to the following:

$$\boldsymbol{p}_i = \boldsymbol{x}_i'\delta_1 + \boldsymbol{d}'\delta_2 + \varepsilon_i \qquad \text{(Equation 2)}$$

where δs are vectors of coefficients of appropriate parameters, and ε is the error term.

It should be noted that Equation (2) differs from Equation (1) in two important aspects. Firstly, $\boldsymbol{d}$ is now a column matrix that has (k x 1) dimensions for k = 1, … K industries (instead of a column matrix of (k-1 x 1) dimension). Secondly, as the constant term is dropped, Equation (2) can be interpreted as a fixed-effects model where the industry effects capture omitted factors. The coefficients of the industry dummies are then normalized as deviations from a weighted mean as follows:

$$\hat{\delta}_2^* = (Z - es')\hat{\delta}_2 \qquad \text{(Equation 3)}$$

where $\hat{\delta}_2^*$ is a column vector of the deviation of each industry's pollution load relative to the national average level; Z is a (k x k) identity matrix; e is a column vector of one; s is a column matrix with the sample share of each industry (i.e., $s_k = n_k / \sum_{k=1}^{K} n_k$ where n_k is the number of firms in industry k); and $\hat{\delta}_2$ is the vector of the industry coefficients estimated from Equation (2).

Moving from Equation (2) to Equation (3) implies that instead of evaluating the industry effects on pollution relative to an arbitrarily omitted industry, they are now interpreted as the deviation from the national average pollution level, controlling for various firm-level characteristics (i.e., vector $\boldsymbol{x}$). Therefore, each resultant inter-industry pollution differential represents the difference between the level of pollution load of a firm in a particular industry k and that of the average firm across all industries in the economy.

To facilitate statistical inferences, the adjusted variance-covariance matrix of the inter-industry pollution differentials $V(\hat{\delta}_2^*)$ (V denotes vector) was computed as suggested by Haisken-DeNew and Schmidt (1997) as follows:

$$V(\hat{\delta}_2^*) = (Z - es')V(\hat{\delta}_2)(Z - es')' \qquad \text{(Equation 4)}$$

The effect of trade on industrial pollution was modelled using the weighted least square (WLS) method as follows:

$$\Psi_k \hat{\delta}_{2k}^* = \Psi_k \partial_o + \Psi_k \boldsymbol{g}_k \partial_1 + \Psi_k \boldsymbol{t}_k \partial_2 + \Psi_k \vartheta_k \qquad \text{(Equation 5)}$$

where $\boldsymbol{g}_k$ is a vector of industry-level characteristics; Ψ_k is the weight given expressed as $\Psi_k = \sqrt{1/V(\hat{\delta}_{2k}^*)}$ as the standard error of $\hat{\delta}_2^*$ calculated as the square root of Equation (4); ∂s are vectors of coefficients of appropriate parameters; and ϑ is the stochastic error term.

Since the dependent variable was estimated from the framework above, we were concerned that the coefficients in Equation (3) would have large variances that were likely to differ across industries, depending on the sampling variances of the estimated pollution differentials. Therefore, a WLS method that assigned lower weights to firms with larger sampling variances was preferred to the OLS (ordinary least square) procedure.

Moving from Equations (1) to (5) reflected the change in focus from the firm to the industry level. In this context, the issue of differentiating between 'dirty' and 'clean' industries became more appropriate. The conventional approach in previous studies has been to identify pollution-intensive sectors as those which have incurred high levels of pollution load or abatement expenditure per unit of output (e.g., see Mani 1996). Another approach has been to rank sectors according to their actual pollution intensities as done by Mani and Wheeler (1999). In this study, pollution-intensive (or 'dirty') industries were identified on the basis of the estimated pollution differentials. Given this, industries that had positive deviations were classified as 'dirty' while those with negative deviations were considered as 'clean'. The merit of this classification was that the inter-industry pollution differentials were estimated while controlling for various firm-level characteristics.

3.2 Data Sources

One distinctive feature of this study was that its analysis was largely based on the raw firm-level data of the 2002 Vietnam Enterprise Survey (VES). This database has been published, but only to a limited extent in GSO 2004 and GSO 2005. The 2002 VES provides a rich source of information at the firm level and on the sectoral characteristics of Vietnam's manufacturing sector, including the year of establishment, sector of operation, type of ownership, capital structure, employment structure, wage bills, main indicators of business activities (such as revenues, profits, and taxes), export markets, and the application of information technology (GSO 2004; 2005). This information was explored to derive a rich set of characteristics at both firm and industry levels which was then used in the framework outlined above. This study was based on a sample of 14,657 manufacturing enterprises.

Although the firms reported on their industrial waste, this information did not include the 'pollution content' of such waste discharges. The World Bank's Industrial Pollution Projection System (IPPS) was therefore employed to derive projections of the pollution loads of the manufacturing firms. The IPPS was developed on the assumption that industrial pollution was determined by the scale of activities, sectoral composition, and technologies employed in the production process. The IPPS 'converts' information on employment, added value, and output into pollution intensities, which is defined as the amount of pollution per unit of activity caused by several pollutants (see Appendix 2 for types of pollutants included in the IPPS). These pollution intensities can then be used as the projected levels of pollution. Further details and discussion on the IPPS are given in Hettige et al. (1995).

Since the IPPS became available to the research community in the mid-1990s, its data has been used in various countries where insufficient data on industrial pollution has proved to be an impediment to setting-up pollution control strategies. There have been a number of applications using the IPPS for projections of industrial pollution (see Laplante and Smits 1998; Aldaba and Cororaton 2002; and Mani and Jha 2005 for cases of Latvia, the Philippines, and Vietnam, respectively). The IPPS uses three pollution coefficients, including (i) output-based coefficients; (ii) value-added-based coefficients; and (iii) employment-based coefficients. Although the pollution intensities projected using any of these coefficients have generally been found to be highly correlated, Hettige et al. (1995) suggest that pollution and employment usually move in the same direction and thus, that employment-based coefficients are probably preferable for pollution projections in developing countries. Given this, the employment coefficients were used to derive the projections of pollution loads in this study[5].

Applying the IPPS intensities needed some mapping exercises as the IPPS codes were classified according to the International System of Industrial Classification (ISIC, Revision 2) at the four-digit level, while the Vietnam Standard Industrial Classification (VSIC) was employed in the 2002 VES. It was required to map these two systems through the medium of the ISIC (Revision 3)[6]. As mentioned in Hettige et al. (1995, p.4) "sectoral intensities are always exponentially distributed, with a few highly intensive sectors and many which have very low intensities". This implies that pollution projections should be done at the most disaggregated level possible. Taking this into account, this study used the pollution coefficients at the four-digit level, which is the most disaggregated level available in the IPPS. The mapping was thus carried out at this level but the results are not discussed here to due to space constraints (they are, however, available from the authors upon request). Finally, as the output data in the IPPS was given in 1987 US dollars, it needed to be converted into VND and deflated to 2002 prices. The 1987 exchange rate recorded by the International Monetary Fund (IMF) in the International Financial Statistics (IFS) database of 78.3 VND to 1 US$ and the GSO's official price indices for 1987-2002 were used to make this adjustment.

As the trade-environment linkage was the major focus of this study, it was important to obtain data necessary to derive an appropriate proxy for trade exposure. Edward (1997, p.6) emphasized the difficulty of constructing reliable measures for trade policy changes: "Despite significant efforts and ingenuity, there hasn't been much progress in this area". In addition to the lack of consensus on openness measures, constructing a good measure for trade openness can be very data-demanding in practice. Given these constraints, the choice of openness measures in empirical studies depends practically on data availability and specific research objectives.

This research adopted weighted-average tariffs as the measure of trade exposure. Vietnam's tariff data is accessible from the United Nations Conference on Trade and Development (UNCTAD) Trade Analysis and Information System (TRAINS). In an attempt to test the sensitivity of the trade effect, we also experimented with other measures of trade outcomes such as import penetration and export orientation, which were available from the 2002 Social Accounting Matrix (SAM). The 2002 SAM was developed and updated by the Central Institute for Economic Management (CIEM) in collaboration with the Nordic Institute for Asian Studies (NIAS) and is currently the

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[5] Although it was also desirable to investigate the sensitivity of the empirical analysis with respect to the IPPS value-added intensities, this was not pursued in this study as the 2002 VES did not provide information on production costs in detail.

[6] The concordance tables published by the United Nations' Statistical Division (available at http://www.un.org) were used as the basis for mapping the IPPS codes onto those of the ISIC Rev. 3, while the textual descriptions of the VES codes and the ISIC Rev. 3 were employed in the second stage.

latest SAM version available for Vietnam[7]. The next section analyzes the empirical results with a focus on the effect of trade on industrial pollution along with impacts of some other factors.

4.0 RESULTS

4.1 Industrial Pollution: A Descriptive Analysis

Using the 2002 VES and the IPPS (as described in Section 3), we found that the overall picture of industrial pollution of Vietnam exhibited a strong spatial pattern with the Southeast, Red River Delta, and Northeast as the most polluted regions (Table 3). The Southeast was responsible for nearly half of the total amount of toxic pollution and one-third of water pollution. Ranking second, the Red River Delta was responsible for around one quarter of the total air pollution and one-fifth of the total water pollution volumes. This pattern mirrors the current structure of industrial output. During the period 1996–2004, the Southeast produced an average of 54% of the total industrial output of the country while the Red River Delta contributed 18% (GSO 1996; 2001; 2006). Meanwhile, the Northeast accounted for less than 5% of the total industrial output in the same period, but its industrial activities nonetheless contributed about 35% to national water pollution volumes and were the source of roughly one-fifth of total air and toxic pollution levels.

Table 3. Industrial pollution levels by region (2002)

Units: tonnes and percentage

	Water	Air	Toxic
Total pollution	637,556	2,471,700	148,362
Regional distribution			
− Red River Delta	20.55	27.47	24.20
− Northeast	35.13	22.66	19.48
− Northwest	0.22	2.27	0.15
− North Central Coast	3.53	15.90	3.79
− South Central Coast	6.09	5.18	6.73
− Central Highlands	0.73	1.16	1.07
− Southeast	29.96	17.07	40.31
− Mekong River Delta	3.80	8.29	4.27

Source: estimated from the 2002 VES and IPPS

Note: Water pollution includes BOD and TSS; air pollution includes SO_2, NO_2, CO, VOC, TP, and PM_{10}; toxic pollution covers all toxic pollutants discharged to air, land, and water. See Appendix 2 for more details.

[7] The earlier SAMs include (i) the IFPRI VIETSAM 1997 constructed between 1996 and 1997 (more information can be found at http://www.ifpri.org/data/VietNam01.htm); and (ii) the earlier 2000 version of the SAM used in this study which was developed by and used in Tarp, Ronald-Holst, and Rand (2003). These two SAMs were both estimated from the official Input-Output Table for the year 1996 and the VLSS 1997/98 (see Tarp, Ronald-Holst, and Rand 2003).

The top ten pollution-intensive industries for 2002 are reported in Table 4. At the aggregate two-digit ISIC level, metal processing (27), paper products (21), chemical products (24), food and beverages (15), plastic and rubber products (25), and textiles and garments (17) were among the most pollution-intensive industries.

Table 4. Top ten polluting industries in Vietnam (2002)

	Water pollution	**Air pollution**	**Total toxic pollution**
	Two-digit industry level		
1	Metal production and processing (27)	Other non-metal mineral products (26)	Chemical and chemical products (24)
2	Paper and paper products (21)	Paper and paper products (21)	Metal production and processing (27)
3	Chemical and chemical products (24)	Food and beverage (15)	Plastics and rubber products (25)
4	Food and beverages (15)	Metal production and processing (27)	Paper and paper products (21)
5	Other non-metal mineral products (26)	Chemical and chemical products (24)	Textiles and garments (17)
6	Plastics and rubber products (25)	Wood, bamboo, rattan products (20)	Other non-metal mineral production (26)
7	Leather tanning and leather products (19)	Textiles and garments (17)	Metal products (28)
8	Recycling, reprocessing (37)	Coke and crude oil (23)	Other transportation equipment (35)
9	Textiles and garments (17)	Furniture production (36)	Electronic and electric equipment (31)
10	Wood, bamboo, rattan products (20)	Other transportation equipment (35)	Furniture production (36)
	Four-digit industry level		
1	Basic iron and steel (2711)	Cement, lime and plaster (2694)	Paper products (2101)
2	Paper products (2101)	Paper products (2101)	Basic chemicals (2411)
3	Casting of iron and steel (2731)	Clay and ceramic (2693)	Textile fibres (1711)
4	Pharmaceuticals, medicinal chem. (2423)	Basic iron and steel (2711)	Basic iron and steel (2711)
5	Non-ferrous metals (2729)	Manufacture of sugar (1542)	Fertilizers (2412)
6	Fertilizers (2412)	Non-ferrous metals (2729)	Cement, lime and plaster (2694)
7	Manufacture of sugar (1542)	Other chemical products (2429)	Pharmaceuticals, medicinal chem. (2423)
8	Fish products (1512)	Vegetable and animal oils (1514)	Motorcycles (3541)
9	Cement, lime and plaster (2694)	Refractory ceramic products (2692)	Artificial fibres (2431)
10	Dairy products (1521)	Basic chemicals (2411)	Pesticides, agro-chemicals (2421)

Source: estimated from the 2002 VES and IPPS

Note: The industries (either at the two or four-digit level) follow the ISIC Rev. 3 classification.

Although these rankings are reported at the two-digit level, our results are generally compatible with Mani and Wheeler's (1999). When pollution rankings were made at the four-digit level, the results showed that chemical industries, including paper products (2101), basic chemicals (2411), fertilizers (2412), pesticides and agro-chemicals (2421), and artificial fibres (2431), and metal production sectors such as basic iron and steel (2711) and non-ferrous metals (2729) were among the top ten pollution-intensive industries. The results are generally in accordance with those of the World Bank (2006a). Essentially, similar rankings were reported in Laplante and Smits (1998) in the case of Latvia.

Table 5. Industrial pollution by enterprise ownership (2002)

Unit: percentage

	Water	**Air**	**Toxic**
Total Vietnam			
Central SOEs	51.70	42.04	38.01
Local SOEs	15.01	33.14	16.64
Domestic private	21.93	15.48	27.29
Foreign-invested	11.36	9.34	18.06
Southeast			
Central SOEs	43.68	30.36	26.93
Local SOEs	7.11	13.19	10.18
Domestic private	27.43	25.85	27.43
Foreign-invested	21.79	30.60	35.46
Red River Delta			
Central SOEs	21.00	52.82	31.85
Local SOEs	28.28	20.89	17.96
Domestic private	35.71	20.45	41.90
Foreign-invested	15.02	5.84	8.29
Northeast			
Central SOEs	86.97	34.12	79.92
Local SOEs	7.23	58.78	12.60
Domestic private	4.43	5.63	5.71
Foreign-invested	1.38	1.47	1.78
Other regions			
Central SOEs	25.86	44.34	24.12
Local SOEs	31.76	36.21	35.85
Domestic private	33.50	12.81	31.04
Foreign-invested	8.88	6.64	8.99

Source: estimated from the 2002 VES and IPPS

Notes:

(1) Stated-owned enterprises are classified according to the authorities that own them (central, municipal or local).

(2) Private sector enterprises are divided into domestic private and foreign-invested sub-sectors; the foreign-invested sub-sector is broadly defined as all enterprises that are partly or totally owned by foreign investors.

Industries contribute to pollution differently according to their type of ownership. SOEs were found to be the most pollution-intensive, especially those under central-level authorities (i.e., ministries or the Prime Minister's Office) (Table 5). As at 2004, central-level SOEs were responsible for nearly half the occurrence of water pollution, and for about 40% of the air and toxic pollution in Vietnam while the foreign-invested sector accounted for roughly 10% of water and air pollution, and 18% of toxic pollution (Table 5). Notably, the central-level SOEs, mainly those established as 'Corporation 90' or 'Corporation 91'[8] during the 1990s, utilized the largest portion of the state capital. They are considered to be the major players in the economy.

4.2 Trade Liberalization and Industrial Pollution at the Firm Level

The dependent variable in Equation 1 was the pollution level (water, air, and toxic pollutants in tonnes given in natural logarithms). Among the regressors, the weighted-average tariff at the four-digit level (given in percentage) was the variable of central interest as it captured the trade effect on industrial pollution. The set of firm-specific characteristics included the input combination (labour and capital), age of establishment (and its quadratic term), and type of ownership (central-level SOEs, local-level SOEs, domestic private sector, and foreign-invested sector). In addition, the number of computers per 1,000 employees and a dummy variable for the use of the internet to do business were also specified to partly control for technology and IT application. The ratio of employees who had signed labour contracts was used as a proxy for the firms' compliance with labour regulations[9]. A variable for the average wage and a dummy for other benefits in addition to wages (such as allowances and bonuses) were introduced to test whether workers in more pollution-intensive firms were compensated by higher wages and non-wage benefits. The ratio of female workers was also included to capture any differences among firms in terms of gender awareness or firm-specific characteristics. To control for location effects, we specified a set of dummies for the eight regions. Finally, the fixed industry effects were also controlled using a set of dummies for two-digit industries[10]. A brief description and associated summary statistics of these variables are provided in Appendix 3.

The estimated effects of the trade variable are reported in the first row of Table 6. The estimates revealed a negative relationship between trade protection and industrial

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[8] 'Corporation 90' refers to an SOE that was established according to Decision 90 of the Prime Minister dated March 7, 1994. Corporations 90 report to the ministers of the appropriate fields. Currently, there are 80 of them. 'Corporation 91' refers to an SOE that was established/restructured in 1994 according to Decision 91 of the Prime Minister dated March 7, 1994. Eighteen Corporations 91 resulted, of which eight have been transformed into state-owned economic groups. These Corporations 91 report directly to the Prime Minister. Corporations 90 are smaller than Corporations 91 in terms of chartered capital and number of member companies. Both Corps 90 and 91 were established by grouping SOEs into large corporations, the ultimate objective of the government being to strengthen the role of SOEs in the economy.

[9] The Labour Code 2002 mandates that all employers must negotiate and sign legal labour contracts with their employees (see Chapter IV of the Labour Code).

[10] We also estimated the model with fixed industry effects at the three-digit level. The resultant estimates were largely identical to what is reported here.

pollution in all cases. On average and ceteris paribus (all other things being equal), a reduction of 10% in the weighted average tariff produced an increase of the pollution level by 0.21% – 0.33%. These estimated effects of the trade variable were well determined at conventional significance levels. The trade effect appeared strongest in relation to air pollution, but was lesser in the case of toxic pollution. The difference among these estimates was, however, not statistically significant (on the basis of a t-test). This finding implies that the liberalization of tariffs exacerbates industrial pollution in Vietnam. In other words, while trade reform has been commonly heralded as one of the main drivers behind the country's impressive growth during the *Doi moi*, the findings of this study show that it has come at the cost of increased industrial pollution. These findings on the negative effects of trade liberalization on the environment in terms of increased industrial pollution are among the first of such evidence in Vietnam. It is thus not possible to discuss our findings in comparison with similar earlier studies in Vietnam.

Table 6. Trade and industrial pollution: regression results at the firm level (2002)

Dependent variable: Pollution intensity (firm-level, tonnes of pollutants in natural log)

	Water	**Air**	**Toxic**
4-digit industry weighted average tariffs	-0.0318***	-0.0329***	-0.0219**
	(0.013)	(0.013)	(0.011)
Employment size	0.4207***	0.3952***	0.3693***
	(0.121)	(0.087)	(0.072)
Capital volume	0.2901***	0.2719***	0.2485***
	(0.084)	(0.077)	(0.029)
Ratio of female employees	-0.1293**	-0.1587***	-0.2485***
	(0.068)	(0.049)	(0.086)
Age of establishment	0.0298***	0.0113***	0.0259***
	(0.008)	(0.004)	(0.005)
Quadratic age of establishment	-0.0745*	-0.0275**	-0.0131
	(0.042)	(0.013)	(0.011)
Central-level SOEs	0.1845**	0.1969***	0.262***
	(0.074)	(0.037)	(0.049)
Local-level SOEs	-0.1226**	-0.0908***	-0.1037**
	(0.055)	(0.025)	(0.048)
Foreign-invested enterprises	-0.0522	-0.1513***	-0.0689*
	(0.08)	(0.034)	(0.038)
Ratio of employees with contracts	-0.0622***	-0.0016	-0.0783**
	(0.007)	(0.003)	(0.039)
Number of PCs per 1000 employees	0.0012	0.0044	-0.046***
	(0.001)	(0.005)	(0.016)
IT application	-0.1149**	-0.1707***	-0.0842**
	(0.059)	(0.026)	(0.039)
Average wage bill	0.0673**	0.0044	0.1499*

	Water	Air	Toxic
	(0.031)	(0.013)	(0.081)
Having other benefits	0.1499**	0.0374	0.1695**
	(0.074)	(0.035)	(0.085)
Red River Delta	0.381***	0.4365***	0.3316***
	(0.086)	(0.041)	(0.079)
Northeast	0.2598***	0.2286***	0.2529***
	(0.102)	(0.051)	(0.055)
Northwest	0.1342	-0.1569	-0.1692*
	(0.3)	(0.145)	(0.091)
North Central Coast	0.1604**	0.2987***	0.2874***
	(0.068)	(0.062)	(0.04)
South Central Coast	0.1581	0.1835*	0.2623***
	(0.111)	(0.125)	(0.031)
Central Highlands	0.1658	0.2063**	0.3542***
	(0.141)	(0.127)	(0.048)
Southeast	0.1911***	0.5238***	0.3929***
	(0.082)	(0.039)	(0.069)
Constant	-0.5574***	0.5746***	0.7109*
	(0.118)	(0.053)	(0.375)
R2	0.7074	0.7747	0.4239
Number of observations	13,747	14,610	14,657

Notes:

(1) ***, **, and * refer to the variables of which the estimated coefficients are statistically significant at 0.01; 0.05; and 0.1 levels respectively.

(2) Huber (1967)-corrected standard errors are in parenthesis.

(3) Fixed industry effects were controlled using the two-digit ISIC Rev.3 classification. The estimated fixed effects are not reported here for brevity.

The negative effects of trade liberalization on industrial pollution as found in this study are also reported in other studies on trade-environment linkages, although most of the evidence was obtained using other approaches. For instance, Ferraz and Young (1999) used an input-output model to estimate industrial pollution and found that pollution intensity had increased during trade liberalization in Brazil in the 1990s. Lee and Roland-Holst (1997), on the other hand, used data from the period 1965–1990 for Japan and Indonesia and analyzed the impact of trade liberalization on industrial pollutants using an applied general equilibrium model. The results indicated that in both countries, export-oriented growth would exacerbate industrial pollution in a country when it had comparative advantage in dirty industries. In addition, trade liberalization would also increase emissions of all major industrial pollutants.

We now turn our attention to other determinants of industrial pollution at the firm level. Input combination was found to have a positive relationship with pollution intensity. Controlling for other factors, an increase by 10% in labour size would raise pollution by 2.5% – 4.4%, which is slightly higher than the effect induced by the same increase in capital. Interestingly, firms with a greater proportion of female employees were less pollution-intensive. In addition, there was an inverted U-shaped relationship between the age of the establishment and pollution load, implying that pollution levels rose over time until the firm reached a turning point. On average, one additional year in a firm's life would create a ceteris paribus increase of 1% – 3%.

As discussed earlier, the central-level SOEs were found to be the major sources of industrial pollution. This is indeed reflected in the estimates in the set of dummies which broadly distinguished firms by type of ownership. It became evident that compared with the domestic private sector, central-level SOEs were considerably more polluting. On average and ceteris paribus, a central-level SOE was 18% – 26% more polluting than an average domestic private firm. In contrast, local-level SOEs and foreign-invested firms were considerably less polluting than their domestic private counterparts by 7% – 15%.

The Labour Code of 2002 mandates the signing of labour contracts for all types of work with either indefinite or definite terms (Chapter IV). Therefore, the ratio of employees with labour contracts was considered as a proxy for a firm's compliance with labour regulations, which also partly reflected the firm's general attitude to other legal regulations including those on environmental protection. The results given in Table 6 suggest that better compliance with regulations was an important factor in controlling pollution. Notably, the estimates suggest that employees in pollution-intensive firms were compensated by higher wages and non-wage benefits.

Furthermore, we also found that firms with IT application and advanced technology were less polluting. On average, firms that developed websites and used email to conduct their daily business produced, ceteris paribus, between 9% – 15% less pollution than those without these applications.

Finally, Table 6 also shows a spatial pattern of industrial pollution. Compared with the Mekong River Delta, other regions exhibit higher pollution loads by 20% – 45% with the highest deviations observed in the Southeast, Red River Delta, and the Northeast. This is, however, not surprising given the geographical distribution of industrial activities as highlighted earlier.

4.3 Trade Liberalization and Industrial Pollution at the Industry Level

The three-digit level was selected for investigating the trade-environment linkage at the industry level instead of the two-digit or four-digit level for practical reasons. If the two-digit level had been chosen, the sample size would have been 23 (industries) which would have been too small for an empirical analysis. Using the four-digit level, on the other hand, would have given us a sample of 205 industries. However, this would also have included some industries with very few firms and thus, the resultant estimates for the inter-industry pollution differentials would probably not have been reliable. Given this, Equation (2) was estimated controlling for the fixed effects of 68 three-digit industries to obtain inter-industry pollution differentials, which were then used to run Equation (3). It should be noted that the inter-industry pollution differentials were obtained after controlling for various individual characteristics of the firms. Therefore, these differentials are expected to have captured differences attributable to unobservable factors, other than firm characteristics, at the industry level.

With the sample of 68 observations, controlling for fixed industry effects at the two-digit level would not have been practical as it would have meant a considerable loss of degrees of freedom. Instead, Equation (5) was estimated controlling for a set of characteristics largely similar to that in Equation (1), except that the variables were now defined at the industry level. In addition, as mentioned earlier, a dummy for ‘dirty’ and ‘clean’ industries was also included as a regressor[11]. Descriptive and summary statistics on these variables are given in Appendix 4.

The results obtained from estimating Equation (5) using the WLS approach are reported in Table 7. The estimated effect of the coefficient for the trade variable can be interpreted as the tariff-pollution elasticity (the change in pollution as a result of one unit change in tariff). The trade-pollution effect was found to be negative and significant, indicating that industries with relatively lower tariff protection tended to discharge relatively more pollutants. When the pollution intensities with respect to output were used, the tariff-pollution elasticity varied from -0.27 to -0.35. This implies that a reduction of 10% in tariffs from the average level of protection in an industry would lead to an increase of 2.7% – 3.5% in the pollution differential of that industry[12]. Similar to the previous results, the strongest trade effect was observed in the case of air pollution. The differences in the coefficients among models (i.e., using different dependent variables) were, however, not statistically significant.

Table 7. Trade and industrial pollution: regression results at the industry level (2002)

Dependent variables: inter-industry pollution differentials given in fractional point

	Water	**Air**	**Toxic**
3-digit industry weighted average tariffs	-0.2907***	-0.3525*	-0.2703**
	(0.125)	(0.201)	(0.112)
Average size of establishments	0.3767**	0.1725	0.2864*
	(0.184)	(0.144)	(0.153)
Average capital of establishments	0.3148	0.4318**	0.2937**
	(0.244)	(0.223)	(0.134)
Average ratio of female employees	-0.1736***	-0.2815*	-0.1885***
	(0.046)	(0.163)	(0.063)
Average age of establishment	0.0746	0.1241**	0.0832***
	(0.06)	(0.056)	(0.022)

[11] To test whether it was statistically justifiable to separate these two sub-samples, we employed a Wald test (using the variance-covariance matrices) for common parameters across the two groups. As shown in Table 8, the null hypothesis of common parameters could not be rejected in all cases (except for the test without the constant term in the water pollution regression using the employment coefficients).

[12] It should be noted that the effects of trade in this case were evaluated using the inter-industry pollution differentials. Therefore, the estimates do not show the ceteris paribus change in the average pollution level as in the previous section (4.2).

	Water	Air	Toxic
Quadratic term of average age	0.1936*	-0.1077	-0.0307
	(0.121)	(0.076)	(0.045)
Share of central-level SOEs	0.4667*	0.2593*	0.3648***
	(0.277)	(0.145)	(0.123)
Share of local-level SOEs	-0.2998*	0.2215	0.1856*
	(0.173)	(2.171)	(0.097)
Share of foreign-invested enterprises	-0.1597**	-0.2238*	-0.1079*
	(0.068)	(0.121)	(0.06)
Ratio of employees with contracts	-0.1641	-0.1846**	-0.1228**
	(0.142)	(0.089)	(0.051)
Average PCs per 1000 employees	-0.0377	-0.0617**	-0.0624**
	(0.075)	(0.03)	(0.028)
Average IT application	-0.0905*	-0.1085***	-0.0635**
	(0.052)	(0.024)	(0.027)
Average wage bill	0.1479***	0.2865***	0.1667*
	(0.056)	(0.103)	(0.086)
‘Dirty’ industry dummy	0.4232**	0.2783	0.3747***
	(0.204)	(0.215)	(0.144)
Constant	-0.6843	-0.4737	-0.4547*
	(0.744)	(2.832)	(0.265)
Unadjusted R^2	0.5197	0.5502	0.6128
Wald Test (1) $\sim \chi^2_{13}$	21.109	18.051	14.978
Wald Test (2) $\sim \chi^2_{14}$	14.572	13.165	17.375
Number of observations	68	68	68

Notes:

(1) The unadjusted R^2 is the squared correlation between the actual and predicted dependent variable in each model.

(2) The Wald test was used to test for common parameters across the ‘dirty’ and ‘clean’ industry groups. Wald Test (1) provided an overall test for dirty-clean differences across all parameters other than the constant term. The Wald Test (2) provided an overall test for dirty-clean differences for all parameters including the constant term.

(3) ***, **, and * refer to the variables of which the estimated coefficients are statistically significant at 0.01; 0.05; and 0.1 levels respectively.

The negative effects of trade liberalization found at the industry level reinforced our earlier findings on the trade-off between trade and environment in the firm-level analysis. In this regard, this study provides more conclusive evidence on the trade-environment linkage in Vietnam than Mani and Jha (2005) where the trade effect was captured by a dummy for pre- and post-USBTA (US-Vietnam Bilateral Trade Agreement) periods. They reported no significant changes in pollution-intensive exports in the post-USBTA period compared to the pre-USBTA period[13]. Our findings contribute to mixed evidence on the trade-environment linkages highlighted earlier. The trade-off between trade liberalization and the environment which we have found in this study on Vietnam has also been found in a number of developing countries such as Bangladesh, Chile, India, Uganda (all in UNEP 1999), and Argentina (UNEP 2001), as well as transition economies like Romania (UNEP 1999) and Russia (Cherp, Kopteva and Mnatsakanian 2003) where trade liberalization as a major component of structural adjustment programmes was reported to exacerbate environmental degradation. A similar story was also reported in China by Dean (2002) although he provided further evidence that trade-induced income growth as an indirect effect of trade liberalization finally outweighed the negative direct effects of trade liberalization on environment.

The estimates in Table 7 reveal the effects of other industry-specific characteristics on the inter-industry pollution differentials and are generally consistent with the results of the firm-level analysis. At the industry level, an increase in the average employment size of an industry by 10% would exert a rise of 2.05% – 4.46% in the deviation of the pollution level of that industry relative to the national weighted average of the manufacturing sector (see Methodology section). The same increase in the average capital of that industry would cause a ceteris paribus increase of 1.5% – 4.32% in that industry's pollution differential. The ratio of female employees was found to be negatively correlated with inter-industry pollution differentials. In addition, an inverted U-shaped relationship between pollution intensity and the average age of the industry was also found.

These results reinforce the fact that central-level SOEs are much more polluting than the domestic private sector. On average and ceteris paribus, an increase in the share of central-level SOEs in an industry by 10% would produce an increase of between 1% – 3% in that industry's pollution load relative to the national weighted average of the manufacturing sector. In addition, we also found evidence that the general compliance of industries with labour regulations helped to reduce industrial pollution. Holding other factors unchanged, a rise of 10% in the average ratio of labour contracts resulted in a 1% – 2% drop in the pollution differentials. The results also revealed a negative relationship between IT application and technology advancement, and pollution in manufacturing industries in Vietnam. Finally, 'dirty' sectors were found to be 30% – 52% more polluting than those with negative inter-industry pollution differentials.

4.4 Sensitivity Analysis of the Trade Effect

The trade effects reported above were measured using tariffs. Trade exposure can also be measured in terms of non-tariff barriers (NTBs). In fact, the process of tariff restructuring is only one part of Vietnam's trade reform and there have been significant changes to NTBs during its transition from a centrally-planned economy to a market economy (see Appendix 1). Quantifying the changes in the NTBs was, however, not

[13] Mani and Jha (2005) used the two-digit industry-level data from the GSO database on industrial activities in the period 1997-2002 to model output (or export and FDI flows) as a function of input combination, pollution load, and dummies for trade liberalization.

possible in this study due to data constraints in computing the tariff-equivalents for the NTBs. In further attempts to test for the sensitivity of the trade-pollution effect, we experimented with two alternative trade variables; (i) the lagged tariff variables used in estimating Equations (1) and (5); and (ii) import penetration and export ratios as outcomes of trade reform.

The use of the current tariffs in the previous analysis was subject to a potential endogeneity problem as certain firms (or groups of them) could lobby effectively for high tariff barriers for their benefit. For the firm-level analysis, we partly addressed this problem by controlling for fixed industry effects, but we did not expect this to work as well for the industry-level analysis given the presence of large and powerful central-level SOEs and foreign-invested firms which were potentially strong lobby groups. We employed the tariff data of 2001 and 1999 (from the UNCTAD TRAINS database) as alternatives for the tariff data in 2002. Re-estimating Equations (1) and (5) using this data provided essentially the same estimates and are not reported here for brevity. At the firm level, the estimates of the coefficients for the trade variables varied from -0.018 to -0.035 and these estimated effects were statistically significant at either the 5% or 1% levels. At the industry level, there were no considerable differences between the previous estimates of the tariff-pollution elasticity and the new estimates using the lagged tariff data. This suggests that the trade-off between trade liberalization and industrial pollution may not be sensitive to the potential endogeneity of tariffs. The fact that these tariff structures were relatively stable in the given years (see Appendices 3 and 5) lends a possible explanation for this finding.

Tariffs are sometimes considered as a poor measure of trade exposure. The reason is that increases in export/output and/or import penetration ratios of a certain sector can happen (meaning higher trade exposure for that sector) without any changes in tariffs. Similarly, a tariff cut in a certain sector may not increase that sector's exposure to international trade if such tariff cut is cancelled out by a decrease in that sector's export and/or import penetration ratio. In further attempts to test for the sensitivity of the trade-off between trade liberalization and industrial pollution, this study employed the 2002 SAM for Vietnam to construct import penetration and export ratios as alternative trade variables. Mirroring the GSO's Input-Output Table in 2000, the SAM 2000 was disaggregated to comprise 112 commodities, of which 68 were manufacturing products (see CIEM and NIAS 2004 for more details). Given this limited number of commodities, it was most appropriate to construct the import penetration and export ratios at the two-digit level. This resulted in a modest number of 21 two-digit ISIC manufacturing industries[14] .

As the import penetration and export ratios were only available for these 21 industries, it made no practical sense to insert these ratios as alternatives for the tariff variables in the firm-level analysis when estimating Equation (1) as they would introduce very little variation between the trade variables among firms. For the industry-level analysis, however, we used these two variables in place of the tariff variables to estimate Equation 5. The results revealed that the estimated effects of most of the other factors (such as size, capital, age of establishment, type of ownership, ratio of contracted

[14] It took another mapping exercise to map these commodities using the two-digit industry codes.

workers, and ratio of female workers) were intact—these are, however, not reported here due to space constraints (they are available from the authors upon request). Instead, we focused on the estimated effects of the export and import penetration ratios. When the import penetration ratio was used, the estimates did not turn out to be statistically significant for toxic and air pollution. But there was a positive relationship between import penetration and the inter-industry water pollution differentials, suggesting that a more liberalized trade regime (i.e., higher import penetration) would result in higher levels of water pollution. In particular, an increase of 10% in the import penetration level of an industry from the national weighted average would lead to an increase of nearly 3% in the level of water pollution by that industry. In the case of the export ratio, the estimated impacts of this variable were significant only in the air pollution regression. An increase of around 2.2% in the level of air pollution produced by an industry was found for an increase of 10% in the export ratio of the same industry.

One possible explanation for the relatively poor performance of these two variables (the export and import penetration ratios) is probably due to their aggregation at the two-digit level (while the estimation was carried out for three-digit industries). Thus, there might not have been sufficiently large variations among observations. More notably, the fact that only 68 manufacturing commodities could be extracted from the 2002 SAM suggests that these ratios might not fully capture the actual levels of import penetration or export orientation. In the four cases (out of six) where the estimated effects of the trade variables were significant, we observed the negative impacts of a more liberalized trade regime on the environment in terms of industrial pollution. Given this, although the sensitivity tests were not really conclusive, the results can nonetheless be taken to suggest some degree of robustness of the trade effects reported in this study.

5.0 CONCLUSIONS

The trade policy reform as one pillar of the reform package since the early 1990s has transformed Vietnam from an import-substituting economy into a highly liberalized one. In this process, Vietnam has made important commitments to both regional and international trade organizations as well as entered into bilateral trade agreements with major trading partners. Joining ASEAN and becoming an ASEAN Free Trade Area (AFTA) member, completing the WTO accession, and signing trade agreements with major trading partners have been milestones in the country’s opening up. Trade reform in particular and the *Doi moi* in general have been heralded as responsible for Vietnam’s success in becoming among the top two or three performers in the developing world (Glewwe, Agrawal and Dollar 2004).

However, environmental economists have reason to worry about this ‘success story’. Rapid growth of labour- and resource-intensive exports and radical changes in trade direction towards trade partners that generally have more restrictive environmental regulations are likely to be harmful to the environment, as suggested by literature and the experiences of some developing countries. Using raw data from the 2002 VES and the IPPS, this study employed a partial equilibrium econometric approach to examine the relationship between trade liberalization and industrial pollution in Vietnam’s manufacturing sector. The results indicate that trade liberalization has a negative impact on the environment as it exacerbates industrial pollution. This trade-off was upheld using lagged tariff data and did not prove very sensitive to the use of import penetration or export orientation ratios as proxies for trade reform. On the basis of the findings of this study, we daresay that trade reform towards a more liberalized trade regime has exacerbated industrial pollution in Vietnam. This is worrying given that Vietnam has recently become the 150th WTO member and further trade liberalization commitments are imminent.

As far as environmental policy is concerned, awareness about the importance and necessity of environmental protection is growing in Vietnam. In recent years, it has been widely recognized that rapid industrial growth has come at a price for the environment (World Bank, MoNRE and CIDA 2004; World Bank 2006a). As higher growth rates are projected over the next five years (MPI 2006), further trade liberalization would be more 'costly' for the environment. In this context, the institutional and legal framework for environmental protection has been gradually developed. In particular, the amended Law on Environmental Protection (effective July 2006), the National Environmental Protection Strategy until 2010, and the Vision Towards 2020 are significant efforts to ensure a balance between economic growth and environmental protection. The National Agenda 21 strategy further provides a basis for more effective coordination between the authorities concerned. The latest Socio-Economic Development Plan 2006-2010 clearly states the aims to "mainstream environmental protection into socio-economic development plans to achieve the sustainable development goals [and….] renew the planning work in regard to environmental protection" (MPI 2006, p.109). The findings of this study combined with the experiences of other developing countries suggest that inadequate awareness of how trade liberalization in particular and economic integration in general can be potentially harmful to the environment in terms of serious and far-reaching consequences.

Having a good awareness of the impacts of trade liberalization on industrial pollution is thus necessary, but setting up policies, introducing instruments, and prioritizing activities to control industrial pollution is not an easy task. The amended Law on Environmental Protection (2006) has set up a framework for the introduction of pollution fees and sanctions to be applied to highly polluting industries, and the use of incentives to encourage the use of clean technologies. However, efforts in these areas are still at an early stage. We expect that before these policies can be effectively implemented, a number of strategic environmental assessments (SEAs), as mandated by the amended Law (Chapter III), will need to be carried out. In undertaking these SEAs, the appropriate authorities should bear in mind the potential impacts of trade liberalization on the environment, especially under the new context of being a WTO member. This would be especially important for the SEAs at the sectoral level as most of the manufacturing industries either lack master plans or have developed master plans without paying adequate attention to possible environmental impacts and the need to implement measures to control pollution[15].

[15] Some examples are the master plan for the garment and textiles sector regulated by Decision 161/1998/QĐ-TTg; and the master plan for the chemical sector enacted by Decision 343/2005/QĐ-TTg.

Although the recent decision by the government to allocate at least one per cent of the state budget for environmental expenditure reflects its commitment and the promise of increasing resources for environmental protection, the resources for controlling and reducing industrial pollution are still limited. In this context, we suggest that priority be given to controlling industrial pollution caused by top polluting industries such as paper products, fertilizers, basic iron and steel, and basic chemicals. The empirical results of this study have highlighted certain aspects that should be taken into account in industrial pollution control measures. Promoting IT application in business activities and technology advancement in the manufacturing sector would be potentially beneficial to environmental protection. Reinforcing the compliance of firms with labour regulations and probably, other types of regulations as well, is likely to also help reduce industrial pollution. In addition, the results indicate that industrial pollution control measures should be directed particularly to central-level SOEs. In this regard, continuing the current SOE reform agenda (as part of the *Doi moi*) and mainstreaming environmental protection in this reform are necessary. However, possible conflicts of interest are likely to occur as the government is both the regulator and owner of the largest SOEs which are among the worst polluters. Therefore, a strong commitment to the SOE reform agenda is essential for success.

Finally, it should be noted that the pollution levels in this study were estimated on the basis of the 2002 VES and the World Bank's IPPS. Although this method has been widely used in instances where data on pollution proved insufficient, it should be borne in mind that the resultant pollution levels here are projected ones and may not fully reflect the actual levels. In addition, as the analysis was formulated on a cross-sectional basis, the environmental impacts of the indirect effects of trade liberalization, such as increased income and growth, have not been measured. Therefore, the empirical findings and resultant policy implications presented in this paper are indicative in nature and need to be interpreted with discretion. Having said that, the indications are strong enough grounds to warrant serious consideration by policy-makers in future decisions on trade liberalization.

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APPENDICES

Appendix 1. Major trade policy reforms during the *Doi moi*

Restrictive measures		Favourable reform measures
	1987	−Vietnam’s first law on import and export duties −Vietnam’s first law on foreign direct investment
−Exports of certain products limited to relevant exporters associations	**1990**	−Special sales tax −Export-import companies required to register
	1991	−Imported inputs used to produce exports exempt from duties −Export processing zones regulation introduced −Export duty on rice reduced from ten to one per cent −Private companies allowed to conduct foreign trade transactions
	1992	−HS (Harmonised Commodity Description and Coding System) system introduced −Vietnam-EU trade agreement
	1993	−Export shipment licensing relaxed −Duty debate system improved −Custom declaration procedure improved
	1994	−Import permits eliminated for all but 15 products −GATT observer status −Licensing procedure reduced; Export shipment licensing removed
−Export taxes raised on 11 products	**1995**	−Import permit system removed −Joined ASEAN/AFTA −Import quota good reduced to seven; export quotas removed, except on rice
	1996	−Maximum tariff reduced to 80% −CEPT/AFTA list published −Managed import foods reduced to six
−Import of sugar prohibited −Temporary prohibitions imposed on consumer goods	**1997**	−WTO accession process started −Rice quotas allocated by provincial government
−Partial surrender requirement imposed and tightened −Special sales taxes reviewed and extended	**1998**	−Decree 57 liberalizing export-import licensing −Management of quota goods shift to tariffs; highest tariff reduced to 60% −Foreign invested firms allowed to export goods that are not registered in their business licenses −CEPT (Common Effective Preferential Tariff) roadmap released −Amendment of export/import duties to introduce 3-schedule tariff, provision of antidumping, countervailing duties; removal of all export duties (except crude oil and scrap metal) −Joined APEC
−Decree 254 adds to list of conditional imports	**1999**	−New tariffs with smaller range and rates released −Surrender requirement reduced

Restrictive measures		Favourable reform measures
	2000	−USBTA signed −Trade promotion established; further reduction on forex surrender rate to 50% −Removal of quantitative import restrictions on 8 out of remaining 19 products −Export-Import Strategy 2001-2020 released for the first time −Re-alignment of control framework on trade to 5-year horizon
	2001	−Removed Quantitative Restrictions (QRs) multilaterally on all tariff lines of the following groups of products: liquor, clinker, paper, floor tiles, construction glass, some types of steel, and vegetable oil −Moved 713 tariff lines from the Temporary Exclusion List (TEL) to the Inclusion List (IL) −Forex surrender rate reduced further to 40%
	2002	−Decision to implement the USBTA, with guidelines for responsibilities and actions −A government negotiation team started working sessions on WTO accession in Geneva −Forex surrender rate reduced further to 30% −Quantitative import restrictions reduced (only four items remain)
	2003	−Introduction of tariff rate quotas (TRQs) for the first time for seven agricultural products −Quantitative import restrictions reduced to sugar and petroleum −Plan to remove forex surrender by 2004

Source: revised from MUTRAP (2002) and Auffret (2003) with updates and additions

Appendix 2. The IPPS's major air, water, and toxic pollutants

Air Pollutants:

- Total Suspended Particulates (TP) and Fine Particulates (PM10): Particulates are fine liquid or solid particles such as dust, smoke, mist, fumes or smog found in air emissions. In heavy concentrations, airborne particulates interfere with proper functioning of the human respiratory system. High levels of ambient TP in urban/industrial areas are therefore associated with greater morbidity and mortality from respiratory diseases. Particulate coatings on leaves inhibit plant growth. High TP concentrations may also force the use of high-cost filtration equipment by manufacturers. Fine particulates (PM_{10}) are less than 10 micron in diameter. They pose the greatest respiratory hazard.
- Sulphur Dioxide (SO_2): Sulphur dioxide is a heavy, pungent, colourless, gaseous air pollutant formed primarily by fossil fuel combustion. It is associated with morbidity and mortality from respiratory disease. In addition, SO_2 is a prime source of the acid rain which has damaged huge forest tracts in the OECD and several transitional socialist economies. Acid rain and runoff have raised the acidity in numerous lakes beyond the point where indigenous fish species can survive. Acid rain also degrades concrete, mortar, marble, metals, rubber and plastics.
- Nitrogen Oxides (NOX): Nitrogen dioxide (NO_2) and nitric oxide (NO) are oxides of nitrogen, often collectively referred to as "NOX." The primary source of NO is thermal combustion of fossil fuels, which emits NO. Higher combustion temperatures, sometimes recommended to reduce emissions of Volatile Organic Compounds (VOCs), are associated with higher production rates of NOX. NOX emissions have important ecological impacts, since they are integral to the formation of acid rain and tropospheric ozone. Inhalation of concentrated NO_2 damages the respiratory tract, resulting in a range of effects from mild reductions in pulmonary function to life-threatening pulmonary oedema.
- Carbon Monoxide (CO): Carbon monoxide is a colourless, odourless, and tasteless poisonous gas produced by incomplete fossil fuel combustion. CO binds with haemoglobin in human blood 200 times faster than oxygen. Thus, the blood's ability to carry oxygen to tissues is significantly impaired after exposure to only small concentrations of CO. High doses of CO can result in heart and brain damage, impaired perception and asphyxiation, and low doses may cause weakness, fatigue, headaches and nausea.
- Volatile Organic Compounds (VOC): The term volatile organic compounds, describes a class of thousands of substances used as solvents and fragrances. VOCs are particularly important in the petrochemical and plastics industries. Human exposure to VOCs is mainly via inhalation, although some VOCs appear as contaminants in drinking water, food, and beverages. Many VOCs are suspected carcinogens. Acute effects from industrial exposures include skin reactions and central nervous system effects such as dizziness and fainting. Recently, sick-building syndrome (SBS) and multiple chemical sensitivity (MCS) have been linked to the relatively low (part per billion) concentrations of VOCs which are more typical of ambient environments. In addition, VOCs may form photochemical oxidants which have been identified as eye and lung irritants.

Water Pollutants:

- Biological Oxygen Demand (BOD): Organic water pollutants are oxidized by naturally-occurring micro-organisms. This 'biological oxygen demand' removes dissolved oxygen from the water and can seriously damage some fish species which have adapted to the previous dissolved oxygen level. Low levels of dissolved oxygen may enable disease-causing pathogens to survive longer in water. Organic water pollutants can also accelerate the growth of algae, which will crowd out other plant species. The eventual death and decomposition of the algae is another source of oxygen depletion as well as noxious smells and unsightly scum. The most common measure for BOD is the amount of oxygen used by micro-organisms to oxidize the organic waste in a standard sample of pollutant during a five-day period (hence, '5-day BOD').
- Suspended Solids (SS): Small particles of non-organic, non-toxic solids suspended in waste water will settle as sludge blankets in calm-water areas of streams and lakes. This can smother plant life and purifying micro-organisms, causing serious damage to aquatic ecosystems. The loss of purifying micro-organisms enables pathogens to live longer, raising the risk of disease. When organic solids are part of the sludge, their progressive decomposition will also deplete oxygen in the water and generate noxious gases.

Toxic Pollutants:

- Toxic Chemicals: Many chemicals in industrial emissions are poisonous to humans, either on immediate exposure or over time, as they accumulate in human tissues. Humans can ingest severely damaging or fatal quantities through repeated exposure, or by consuming plants or animals in which these compounds have accumulated. Toxic chemicals may cause damage to internal organs and neurological functions; can result in reproductive problems and birth defects; and can be carcinogenic. Quantities and length of exposure necessary to cause these effects vary widely. Benzene and asbestos are known carcinogens linked to leukaemia and lung cancer.
- Bio-accumulative Metals: In bio-accumulation, relatively low concentrations of contaminants in air, water, soil and plants become far more concentrated further up the food chain. Some metals can be converted to organic forms by bacteria, increasing the risk that they will enter the food chain. Bio-accumulative metals are particularly dangerous because they are dissipated very slowly by natural systems. They may cause both mental and physical birth defects. Metals can also become rapidly oxidized and converted to soluble form when sediments are exposed to oxygen. Some of the metals which are commonly measured and particularly dangerous are mercury, lead, arsenic, chromium, nickel, copper, zinc and cadmium.

Source: Hettige et al. (1995), p 22-24

Appendix 3. Descriptive and summary statistics (firm-level analysis)

Variables	Brief description	Mean (SD)
Water pollution	Ln of pollution level, PIs with respect to employment	10.671 (4.247)
Air pollution	Ln of pollution level, PIs with respect to employment	12.026 (2.312)
Toxic pollution	Ln of pollution level, PIs with respect to employment	9.213 (2.454)
Water pollution	Ln of pollution level, PIs with respect to output	11.182 (4.706)
Air pollution	Ln of pollution level, PIs with respect to output	12.128 (2.785)
Toxic pollution	Ln of pollution level, PIs with respect to output	9.2411 (3.150)
Weighted average tariff 2002	Weighted average tariff (%), obtained from TRAINS	19.255 (20.08)
Weighted average tariff 2001	Weighted average tariff (%), obtained from TRAINS	20.420 (21.33)
Weighted average tariff 1999	Weighted average tariff (%), obtained from TRAINS	20.868 (22.25)
Employment size	Ln of employment size (1000 employees)	3.4187 (1.540)
Capital volume	Ln of total capital (mil. VND)	6.7768 (2.084)
Ratio of female employees	Ratio of female employees in total employment	0.3705 (0.362)
Age of establishment	Age of the firm (years)	5.3723 (7.853)
Quadratic age of establishment	Quadratic terms of age of the firms divided by 100	0.9052 (3.025)
Central-level SOEs	=1 if central-level SOE, = 0 otherwise	0.1130
Local-level SOEs	= 1 if local-level SOE, = 0 otherwise	0.3844
Domestic private enterprises	= 1 if domestic private, = 0 otherwise	0.3890
Foreign-invested enterprises	= 1 if FDI firm, = 0 otherwise	0.1136
Ratio of employees with contracts	Ratio of employees who signed work contracts	0.3929 (0.187)
Number of PCs per 1000 employees	Number of PCs per 1000 employees	6.8756 (19.01)
IT application (website, email)	= 1 if using website, email in business transaction, = 0 otherwise ok	0.3386
Average wage bill	Average wage bill over a year given in natural log	5.4754 (1.933)
Having non-wage benefits	= 1 if having non-wage benefits, = 0 otherwise	0.0965
Red River Delta	= 1 if located in Red River Delta, = 0 otherwise	0.2632
Northeast	= 1 if located in Northeast, = 0 otherwise	0.0507
Northwest	= 1 if located in Northwest, = 0 otherwise	0.0045
North Central Coast	= 1 if located in North Central Coast, = 0 otherwise	0.0384
South Central Coast	= 1 if located in South Central Coast, = 0 otherwise	0.0564
Central Highlands	= 1 if located in Central Highlands, = 0 otherwise	0.0188
Southeast	= 1 if located in Southeast, = 0 otherwise	0.3863
Mekong River Delta	= 1 if located in Mekong River Delta, = 0 otherwise	0.1817
Number of observations	Number of the firms	14,657

Source: variables constructed from the 2002 VES and IPPS

Notes: (1) Standard deviations (SD) of continuous variables are reported in parenthesis.

(2) Ln = natural logarithm; PIs = pollution intensities

Appendix 4. Descriptive and summary statistics (industry-level analysis)

Variables	Brief description	Mean (SD)
Water pollution differentials	Inter-industry differentials (PIs employ.)	-0.2036 (3.478)
Air pollution differentials	Inter-industry differentials (PIs employ.)	-0.2402 (2.031)
Toxic pollution differentials	Inter-industry differentials (PIs employ.)	0.7576 (0.432)
Import penetration ratio	Ratio of imports to total output of the sector	0.384 (0.232)
Export ratio	Ratio of exports to total output of the sector	0.19 (0.167)
Average size of establishments	Average employment size of firms in the sector (ln)	4.802 (0.781)
Average capital of establishments	Average capital of firms in the sector (ln)	9.2568 (1.37)
Average ratio of female employees	Average female ratio in the sector	0.3776 (0.209)
Ratio of employees with contracts	Average contract ratio in the sector	0.8323 (0.196)
Share of central-level SOEs	Share of central-level SOEs in the total output	0.2953 (0.191)
Share of local-level SOEs	Share of local-level SOEs in the total output	0.1731 (0.119)
Share of domestic private enterprises	Share of domestic privates in the total output	0.3820 (0.162)
Share of foreign-invested. enterprises	Share of FDI firms in total output	0.2496 (0.163)
Average age of establishment	Average age of firms in the sector	6.0264 (3.414)
Quadratic term of average age	Quadratic terms of the avg. age divided by 100	1.2917 (2.217)
Average PCs per 1000 employees	Average PCs per 1000 employees in the sector	11.537 (11.304)
Average IT application	Average share of firms with IT application	0.4735 (0.22)
Average wage bill	Average wage bills of firms in the sector (ln)	7.5872 (0.937)
Having non-wage benefits	Ratio of enterprises having non-wage benefits in the sector	0.0865 (0.026)
Number of observations	Number of 3-digit manufacturing sectors	68

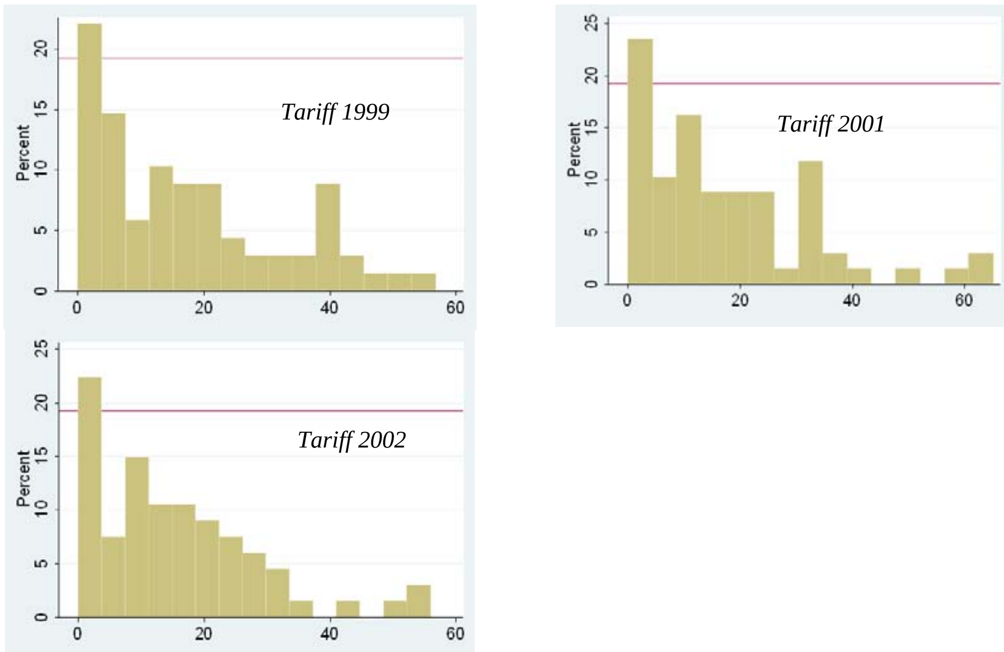
Source: variables constructed from the 2002 VES and IPPS

Notes:

(1) Standard deviations are reported in parenthesis.

(2) P1s employ = pollution intensities with respect to employment; ln = natural logarithm

Appendix 5. Histograms of tariff structures (1999-2002)



Source: compiled from the TRAINS database for the years 1999, 2001, and 2002

Note: The horizontal lines represent the average tariff levels which are consistent with those reported in Appendix 4 above.