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ESSAYS IN TRADE AND ENVIRONMENT: THE ENVIRONMENTAL EFFECTS OF INTRAINDUSTRY TRADE

By

Sarma Binti Aralas

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ABSTRACT

ESSAYS IN TRADE AND ENVIRONMENT:
THE ENVIRONMENTAL EFFECTS OF INTRAINDUSTRY TRADE

By

Sarma B. Aralas

Environmental concerns are at the center stage of current global debates on issues ranging from climate change to natural resource conservation. Anthropogenic sources of environmental degradation include development activities undertaken to increase economic growth and welfare. In the late twentieth century, industrialization characterized the developmental paths of countries seeking to modernize and to raise per capita incomes. Countries that engage in international trade expand their potential beyond domestic borders to reach a global and richer market. As globalization becomes an important aspect of economic development, countries with accelerated growths in dirty industries are viewed as contributing to the deterioration of environmental problems such as global warming, deforestation and resource depletion. Globalization, it is argued, leads to the expansion of pollution-intensive production which causes harm to the environment.

It is widely recognized that international trade raises economic welfare. The succeeding question is, if production is pollution intensive, does international trade necessarily lead to detrimental effects on the environment? Is there evidence to suggest that trade is beneficial or harmful to the environment?

This dissertation explores the environmental implication of the engagement of trade in differentiated, dirty goods. The first essay entitled *Monopolistic Competition,*

Trade and the Environment, presents three analyses. First, it develops a trade-and-environment framework for an economy that produces differentiated, pollution-intensive (or dirty) goods. The production of dirty goods is shown to lead to three environmental effects, namely, the scale, technique and selection effects. Second, it presents a comparative statics analysis of the effects of a change in environmental policy on the firm's level of abatement, product price, consumption, the scale of production and the number of firms in the economy. Third, it examines the relationship between openness to trade and the environment. The impact of intra-industry trade is shown to be the sum of the scale, technique and selection effects. In the second essay, *Intra-industry Trade and the Environment*, the general framework developed in the first essay is modified to allow for a constant-elasticity of substitution (CES) utility function. It shows, unambiguously, that free trade does not lead to detrimental environmental effects. A comparative statics analysis shows that an increase in the stringency of environmental policy generates a negative technique effect and neutral scale and selection effects. In the third essay, *How Does Intra-industry Trade Affect the Environment?*, the integrated theoretical predictions of the pollution models of intra-industry as wells as inter-industry trade are tested using panel-data methods. Statistical evidence suggests the following. First, the emissions of sulfur oxides, nitrogen oxides and volatile organic compounds are increasing in the selection, scale, technique and composition effects. Second, the selection effect is an important and relevant variable in the estimation of the full impact of international trade on emissions level. Third, results conform to the realizations of data generated by the framework of intra-industry as well as of inter-industry trade. Fourth and finally, greater openness to trade or increased trade liberalization, leads to a decrease in emissions level.

To my beloved parents,

Hajah Khadijah Baring Atick and Haji Mohammad Imran Aralas Kua,

and my loving son,

Ibrahem Ghani Wasti

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Trade and Pollution

Recent events have regenerated interest in global environmental concerns. In October 2007, the Norwegian Nobel Committee awarded its Peace Prize in recognition of research on climate change. In the United States of America, California signed into law two pieces of legislations in September 2007, Chaptered Bill 185 (Senate Bill 97) and Chaptered Bill 178 (Senate Bill 85). Both bills address the effects of greenhouse gases (GHG) on climate change.

Environmental disruptions such as the problem of global climactic change are the results of both man-made and natural causes. Notably, the problem of environmental pollution is not confined to the effects of greenhouse gases. Other major pollutants such as lead, nitrogen dioxide, particulate matter and sulfur dioxide can impose physical and financial costs on the environment. The Institute for Agriculture and Trade Policy (IATP) and the Minnesota Center for Environmental Advocacy (MCEA) report that pollution costs Minnesota $1.5 billion annually in childhood diseases (IATP and CEA 2006). The World Health Organization (WHO) Regional Office for Europe calculates that air pollution with particulate matter (PM) shortens life expectancy by 8.6 months for every person in the European Union (EU) and that a reduction in the number of deaths from PM could save the EU an amount of €58-161 billion (WHO Press Release 2005).

Economic development is often cited as a reason for the degradation of the environment. The two fastest growing economies in the world today, China and India, are countries experiencing simultaneous growths in international trade. According to the World Bank (2006), China and India represent a third of global pollution. In the period between 1992 and 2002, China's emissions levels increased by 33 percent and India's emissions levels increased by 57 percent (World Bank Little Green Data Book 2006). Between 2000 and 2005, China's exports increased from 23 percent of GDP in 2000 to 37 percent of GDP in 2005, while India's exports increased from 13 percent to 20 percent in the same period (World Bank Statistics 2006).

This dissertation examines the effects of intra-industry trade on the environment. It investigates the relationship between "new trade theory" and environmental quality in three essays entitled *"Monopolistic Competition, Trade and the Environment"*, *"Intra-industry Trade and the Environment"*, and *"How Does Intra-industry Trade Affect the Environment?"*.

Literature suggests studies that examine the link between trade and environment under "new trade" theory are relatively scarce. In contrast, the majority of models that examine the effects of international trade on the environment are based on the traditional theory of trade.

Traditional trade theory indicates trade is driven by relative factor differentials across countries such that a country specializes in the production of goods in which it has comparative advantage. Under the traditional trade framework, technology yields constant returns to scale in production and markets are characterized by perfect competition. In this setting, countries exchange homogenous goods with each other.

The increasing worldwide trend in the trade of differentiated products suggests intra-industry trade is an important phenomenon in the global exchange of goods. It explains a significant volume of trade flows for countries that engage in intra-industry trade or trade in differentiated products. "New trade" theory describes trade as being driven by the demand for, and the specialization in, differentiated goods where fixed cost allows increasing returns to scale in production. Under these assumptions, trade may occur between countries with similar technologies and similar factor endowments, rather than between countries that are dissimilar in both aspects.

A survey of literature suggests current models in trade-environment literature have not addressed the following major questions. First, how does intra-industry trade affect emissions level in the economy? This question has yet to be explored both theoretically and empirically. Second, in a model of intra-industry trade, does the stringency in environmental policy affect the monopolistically competitive firm's abatement process, its product price, its scale of production, consumption of goods and the number of firms in the economy? Finally, is free trade in differentiated, final goods beneficial to the environment?

This dissertation attempts to fill the gaps in literature by addressing the aforementioned questions. First, it shows that trade in differentiated goods can be decomposed into in a scale effect, a technique effect, and a selection effect. Notably, the selection effect distinguishes the effect of intra-industry trade on the environment from the effects of inter-industry trade on the environment. In addition, the framework developed in this dissertation assumes firms are engaged in the abatement of pollution. Previous pollution models of intra-industry trade have not incorporated the firm's abatement process in linking new trade to the environment. Second, the framework is the first to provide theoretical underpinnings to describe how changes in structural factors impact the emissions level of local pollutants in both the closed and open economy contexts. Third, this dissertation presents an empirical investigation of how intra-industry trade affects environmental quality. It considers data from 26 countries in the Organization of Economic Cooperation and Development (OECD), namely, Australia, Canada, Czech Republic, Germany, Denmark, Finland, France, Greece, Hungary, Iceland, Italy, Japan, the Republic of Korea, Mexico, Norway, New Zealand, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States of America. Three types of pollution are considered: sulfur oxides (SOx), nitrogen oxides (NOx) and volatile organic compounds (VOC). The study period spans the years 1995 through 2004.

This chapter provides a condensed overview of three essays in the dissertation. The first essay is presented in Chapter Two. It proposes a pollution model of intra-industry trade. The second essay, presented in Chapter Three, modifies the model in Chapter Two by using a utility function that has constant elasticity of substitution (CES). The third essay, presented in Chapter Four, is an empirical analysis that tests the theoretical predictions of the models developed in Chapters Two and Three.

In Chapter Two, I develop a model of pollution and trade which assumes that firms engage in the production of dirty goods to take advantage of the consumer's preference for variety. Market structure is imperfectly competitive such that firms are able to capture the benefits of creating a niche through the uniqueness of their products. Cost minimization in production is driven by economies of scale which allows the firm to compete and retain market share. In this setting, I show the following results. First, when the firm internalizes the cost of emissions abatement, the quantity of output produced decreases. One explanation is that the firm incurs higher costs as it complies with environmental regulation. This reduction in output level seems beneficial to the environment since less output implies less emissions generated in the joint production of dirty goods.

Second, the model explicitly and formally makes distinct the environmental impact of dirty production in a monopolistically competitive market, from that in a perfectly competitive market. I show that when firms have market power, and entry and exit of firms prevail, the number of firms in the industry influences the total level of emissions in the economy. New trade theory refers to the change in the number of firms as the "selection" effect. In the pollution model, I show an "environmental" selection effect. Further, I show that openness to trade lead to a smaller number of domestic firms when the economy faces competition from abroad. This finding recognizes the selection effect as part of the impact of international trade on the environment.

Third, I show in Chapter Two that under the assumption of monopolistic competition and increasing returns to scale, the aggregate impact of pollution-intensive production is the sum of three environmental effects, namely, the scale, technique and selection effects. A positive scale effect is generated when the firm expands the scale of production. A negative technique effect is obtained when the firm undertakes abatement activities to lower emissions intensity in production. Finally, a negative selection effect is generated when the number of firms decreases due to increased competition which leads to negative profits.

A fourth contribution of Chapter Two is the comparative statics analysis of the effects of an increase in emission tax rate. I show that when firms engage in pollution-intensive production and undertake abatement activities to comply with environmental policy, a higher emissions tax rate has the following consequences: (i) emission intensity decreases as the firm undertakes greater abatement level to comply with stricter regulation. This is a policy-induced technique effect; (ii) price level rises as production cost increases due to, one, increased emissions tax payments, and two, the increased resources allocated towards abatement activities; (iii) the quantity of output contracts for two reasons: one, higher production costs imply less supply, and two, quantity demanded falls as price increases. This is a policy-induced scale effect; (iv) consumption level decreases due to: one, when firms impose higher prices, demand decreases in quantity, and two, there is a trade-off between allocating resources towards the production of goods for consumption versus allocating resources for the purpose of pollution abatement; (v) the number of firms in the economy increases for the reasons that when a higher emissions tax rate is imposed, production cost increases due to larger emissions tax payments and greater amount of resources allocated towards abatement activities. Consequently, for some firms, the increase in costs is not sustainable as higher price implies less quantity demanded and thus, less revenue. In this case, firms that earn negative profits leave the industry. The exit of some firms implies surviving firms take advantage of economies of scale to expand production by hiring excess labor in the factor market. Positive economic profits earned by surviving firms attract new firms to enter the industry. In the long run, zero economic profits imply an increase in the number of firms. This is a policy-induced selection effect.

In short, the trade-environment framework developed in Chapter Two shows that the increase in the stringency of environmental policy generates the policy-induced scale, technique and selection effects. The policy-induced scale effect is negative if a higher emissions tax rate leads to a fall in the scale of production; the policy-induced selection effect is positive if the higher emissions tax rate leads to a greater number of firms engaged in dirty production in the economy; and the policy-induced technique effect is negative if the stricter policy leads to greater abatement and a subsequent fall in emission intensity.

The analysis further shows that the full impact of an increase in the stringency of environmental policy is the sum of the policy-induced technique, scale and selection effects. This result implies that policy implementation needs to take into account not only the effects of policy on abatement activities (technique effect) and the scale of production (scale effect), but that it also needs to take into account the number of firms that are engaged in pollution-intensive production (selection effect). The magnitudes of each of the policy-induced environmental effects determine the overall impact of policy change on environmental quality.

A surprising result of the comparative statics analysis in Chapter Two is that while the total effect of stricter environmental policy may increase, decrease or leave unchanged aggregate emissions level, its effect on the product price is unambiguous:

more stringent policy leads to higher product price. Therefore, while the effectiveness of tightening regulation is uncertain in terms of improving environmental quality, its effects on the cost of production and the level of consumption are definite: it increases product price and decreases the quantity of goods demanded.

Finally, in Chapter Two, I show that in the open economy case, free trade in differentiated goods generates trade-induced scale, technique and selection effects. When trade opens, countries expand production, but the number of firms in the economy falls as firms face competition from abroad. Consumers demand less of each of the domestic varieties as they choose to consume more varieties in the forms of both local and imported brands. In addition, under the assumption environmental quality is a normal good, I show that when income rises with trade, this implies stricter environmental regulation which leads to increased pollution abatement and lower emission intensity. Finally, in the globalized economy, analysis shows that the full impact of international trade on the environment is the aggregate or sum of the trade-induced scale, technique and selection effects.

In the subsequent Chapter Three, I propose a trade-environment framework using the assumption of a constant elasticity of substitution (CES) utility function. This assumption differentiates the CES model from the previous framework developed in Chapter Two. The non-homothetic, additively separable utility function in Chapter Two is replaced by the homothetic CES utility function. The main advantage of using the CES utility function is that it offers tractability in analysis. The model yields different results: when there are many firms in the industry (n is large), the CES assumption leads to a constant markup of price over marginal costs. It also leads to a constant level of output under the assumption of zero profit in the long run equilibrium.

In the CES framework, comparative statics effects of stricter environmental policy in the form of higher emissions tax rate leads to an increase in the level of abatement. This implies a negative technique effect. However, a change in emission tax rate is found to have neutral effects with respect to scale and selection. On the other hand, and interestingly, a higher emission tax rate is shown to lead to a decrease in net output, which is the output allocated for the purpose of consumption. This result is consistent with the negative technique resulting from higher emissions tax rate. One explanation is that an increase in the use of output as a resource into abatement activities implies a decrease in the allocation of output that can be marketed as consumption goods.

In the open economy setting, free trade is shown to have no effect on product price or on the scale of production. Further, the analysis shows that under both the autarky and open trade settings, the environmental impact of pollution-intensive production is neutral with respect to the scale, technique and selection effects.

Furthermore, in the analysis of Chapter Three, I am able to show that in the case of an endogenous emissions tax rate, an increase in wage rate or income level, raises the emissions tax rate. This result conforms to the theoretical expectation that an increase in income leads to more stringent environmental policy. The result is also consistent with the hypothesized Environmental Kuznets Curve (see Grossman and Krueger 1993) and the pollution haven hypothesis.

In summary, the two models developed in Chapter Two and Chapter Three show that, on one hand, different forms of utility functions lead to diverging results in terms of how intra-industry trade affects the environment. On the other hand, both frameworks show that the full impact of pollution-intensive production is the sum of three environmental effects, namely, the scale, technique and selection effects. Further, the analyses in Chapter Two and Chapter Three show that the aggregated effects of trade cannot be determined unambiguously. In other words, theoretical analysis does not provide a definite answer to the question of how international trade affects environmental quality. However, the analytical results and theoretical predictions can be used to conceptualize an empirical model of the trade-environment linkage.

In Chapter Four, I undertake an empirical analysis to attempt a quantification of the effects of international trade on the emissions levels for countries in the Organization for Economic Cooperation and Development (OECD). Member countries in the OECD are known to engage intensively in the trade of differentiated goods. I distinguish my empirical investigation from previous studies by assuming that most countries engage in both intra- and inter-industry trade. Therefore, the empirical specifications in Chapter Four include variables that explain both types of international trade, that is, both inter- and intra-industry trade. Moreover, the analysis recognizes that data considerations are an important part of the reasons why empirical specifications need to control for variables that influence the environmental impact of trade in both homogeneous and differentiated goods.

In the empirical essay, I posit the following hypotheses concerning the trade-environment relationship: the quality of the environment is increasing in four environmental effects of trade, namely, the scale, technique, selection and composition effects. To test the hypotheses, I adopt empirical models that can capture the data generating process of trade that is driven by both cross-country relative factor differentials and by cross-country preferences for differentiated goods.

Regression results show there is evidence to support the postulated empirical relationships. In particular, I show that there is strong evidence to suggest that the selection effect is a relevant variable in the estimation of the full impact of international trade on environmental quality. Statistically significant results are consistent across six empirical models for three types of pollutants: sulfur oxides, nitrogen oxides, and volatile organic compounds. This study is the first to test the environmental effects of intra-industry trade, and is the first to provide evidence of the importance of controlling for the environmental selection effect. Further, I am able to show strong evidence to suggest that the scale and technique effects can be explained by the assumptions of homothetic production and homothetic consumption functions. These findings are consistent with the framework of intra-industry trade. Equally interesting, the estimations also indicate evidence to suggest that the composition effect can be explained by assumptions consistent with the framework of inter-industry trade. Hence, the analysis support the empirical proposition that both intra- and inter-industry trade affect environmental quality.

1.2 Contribution

The contributions of this dissertation include the following. In Chapter Two, I develop a trade-environment model describing the relationship between intra-industry trade and environmental quality. In the autarky case, I show that the effect of pollution-intensive production of differentiated goods can be decomposed into scale, technique and selection effects. Further, I show that stricter environmental policy increases product price and decreases consumption level, but is ambiguous in terms of its aggregated effects on environmental quality. The aggregate impact of a change in environmental policy is shown to be the sum of policy-induced scale, techniques and selection effects. In the open-economy case, I show that the total impact of intra-industry trade is the sum of trade-induced positive scale effect, negative technique effect and negative selection effect.

In Chapter Three, I build a CES model of pollution and intra-industry trade. In the closed economy case or autarky, I show that a more stringent environmental policy leads to greater abatement activities but is neutral with respect to the scale of production and the number of firms. In the open economy case, I show that the impact of intra-industry trade on environmental quality is neutral with respect to abatement levels, the scale of production and the number of firms. This finding implies that in the CES model, intra-industry trade has no detrimental effects on the environment.

In Chapter Four, I propose an empirical model based on the frameworks developed in the previous chapters. The model tests the theoretical predictions of the integrated environmental effects of both intra- and inter-industry trade. Empirical results provide statistically significant evidence of the environmental selection effect. This finding confirms the importance of controlling for the number of firms in the estimation of the full impact of international trade on environmental quality. There is also evidence to support the assumptions of homothetic production and consumption functions, consistent with the assumptions of the pollution frameworks of intra-industry trade developed in this dissertation.

Finally, I note that for future research, the proposed pollution models can be extended to address trade issues such as firm-level heterogeneity. The incorporation of heterogeneity may be used to analyze the effects of productivity differentials on environmental factors, including abatement levels and emission intensity, in addition to the firm's revenue, profit level and scale of production. Such analysis may be useful in the investigations of current environmental phenomena including the "race to the bottom" in environmental policies, and the pollution haven hypothesis.

CHAPTER TWO

MONOPOLISTIC COMPETITION, TRADE AND THE ENVIRONMENT

2.1 Introduction

In this paper, I develop a model to examine the environmental impact of international trade using new trade theory. The framework explores the trade-environment relationship by analyzing the structural link between pollution and economic variables. The analysis delineates an explicit decomposition of the impact of pollution intensive production into three types of environmental effects, namely the "scale", "technique" and "selection" effects. In addition, the paper presents a comparative statics analysis of the effects of an increase in the stringency of environmental policy which generate "policy-induced" scale, technique and selection effects. In the open economy, the impact of intra-industry trade is shown to generate "trade-induced" scale, technique and selection effects.

The framework developed in this paper explicitly defines and analyzes the environmental impact of trade in a model of monopolistic competition and increasing returns to scale. It advances new insights on trade-environment linkage as it seeks to provide a more definitive answer to the ongoing debate of whether trade is beneficial or detrimental to the environment. The paper contributes to current literature in the following way. First, it develops a framework which shows the explicit decomposition of the impact of new trade on pollution levels. The environmental impact of intra-industry trade is made distinct and is differentiated from the environmental impact of inter-industry trade. Second, the paper is the first to show how trade in differentiated, dirty goods generates trade-induced scale, technique and selection effects. Third, the paper contributes to policy analysis by investigating the effects of an increase in the stringency of environmental policy on emissions level. More specifically, environmental policy is shown to have unambiguous effects on economic variables including the level of abatement, price level, the scale of production and the number of firms or the number of product varieties.

The results of the analysis of this paper are the following. First, intra-industry trade is shown to lead to four effects: one, it leads to an expansion in the firm's scale of production which in turn leads to an increase in the level of pollution. Thus, holding all other factors constant, growth in the economy yields a trade-induced environmental scale effect that is positive; two, trade implies an increase in the level of income which leads to a negative technique effect. That is, holding other factors equal, income growth leads to an increase in firm-level abatement activity which lowers emission intensity; three, trade leads to a fall in the number of domestic firms, which implies a negative trade-induced selection effect. That is, ceteris paribus, a fall in the number of domestic firm leads to a fall in emissions level; and finally, four, the total impact of intra-industry trade on the environment is the sum of the magnitudes of the trade-induced scale, technique and selection effects. Second, the comparative static effects of an increase in the stringency of environmental policy shows that an increase in an emission tax rate have the following unambiguous effects: one, it increases the firm's level of abatement activity; two, it lowers pollution emission intensity; three, it raises product price; four, it increases the number of firms (or equivalently, the number of product varieties); and five, it decreases the firm's scale of production. Further, the analysis shows that the total effect of a change in environmental policy is the sum of the policy-induced scale, technique, and selection effects.

Third, this paper offers new insights which suggest that the environmental impact of trade in differentiated goods needs to be accounted for in characterizing and in measuring the impact of international trade on the environment. Since it is widely acknowledged that most countries engage in both intra- and inter-industry trade, economic factors that influence the effect of trade on environmental quality may characterize not only the equilibrium of the production of inter-industry goods, but also the equilibrium of the production of intra-industry goods. Trade literature suggests that trade patterns under new trade theory are distinct from trade patterns under traditional trade theory. In a similar vein, the environmental impact of international trade under the "new" or "modern" trade theory needs to be distinguished from the environmental impact of international trade under the "traditional" framework. Additionally, the current analysis suggests that trade-induced environmental effects are influenced by economic factors that characterize trade driven by demand aspects rather than by pricing differentials across countries. Equally interesting, the analysis shows that policy-induced environmental effects stemming from more stringent environmental regulation are influenced by determinants that affect market structure and increasing returns rather than by determinants that affect factor intensity in production. The aforementioned differences between the environmental impacts of intra- and inter-industry trade suggest the importance of identifying the distinct effects of new trade from the effects of traditional trade. This distinction can be particularly useful in improving the precision of the empirical modeling of trade-environment relationships.

This chapter is organized as follows. Section 2.2 presents a literature review, section 2.3 describes the framework, section 2.4 presents a comparative static analysis of the effects of changes in environmental policy, section 2.5 presents the open economy model of trade-and-pollution and section 2.6 concludes.

2.2 Literature Review

In the last few decades, economic globalization has brought increased welfare to trading nations (Baldwin 1992). In particular, trade liberalization in developing economies has led to accelerated development and rapid economic growths which have brought modernization and improvements in standards of living. While global economic integration and income growths are shown to have increased consumer welfare, issues have been raised pertaining to the desirability of international trade as it relates to economic and environmental sustainability (Chichilnisky 1994; Strutt and Anderson 2000). The growing concerns of environmental degradation due to market expansions and economic activities have led to studies that attempt to answer the question: is international trade beneficial given the environmental consequences of economic development and the detrimental effects of pollution-intensive production?

Studies that investigate the relationship between international trade and the environment began as empirical investigations. The central underlying question investigated is whether the economic benefits of international trade are counteracted by the harmful effects of the exchange of dirty goods across borders. Early studies investigate the costs of environmental abatement (Walter 1973) and the pollution content of imported goods relative to export goods (Robinson 1988). Subsequent literature suggests that the relationship between international trade and the environment may be described by a number of empirical observations, including trade-environment phenomena such as the dirty industry migration (Low and Yeats 1992) or the pollution-haven hypothesis (Mani and Wheeler 1999), the environmental Kuznets curve (Grossman and Krueger 1993), and the race-to-the bottom argument (Wilson 1996; Sheldon 2006).

To date, empirical investigations have generated mixed findings on whether trade increases economic welfare given the damaging effects of pollution (Stern and Common 2001; Wheeler 2001). The relationship between income growth and environmental quality, now known as the environmental Kuznets curve (EKC), was first described in the seminal study by Grossman and Krueger (1993). The authors provide evidence that environmental indicators such as sulfur dioxide concentrations increase in the initial phase of economic growth but decrease in the later phase of development, with a turning point at an estimated per capita income of about $8,000. While the interesting findings of Grossman and Krueger (1993) give impetus to further and expansive research in the area, new data and more sophisticated statistical methods in subsequent studies do not provide conclusive findings as to the validity of the environmental Kuznets curve (see Shafik 1994; Harbaugh et al. 2002; Stern 2004).

Subsequent investigations into other trade-environment phenomena such as the pollution haven and the race to the bottom hypotheses face similar mixed findings. The phenomenon known as the pollution haven hypothesis postulates that more developed nations relocate dirty industries to less developed nations (LDCs) to take advantage of lax environmental protection as they face more stringent environmental policies at home. In contradiction to the pollution haven hypothesis, Leonard and Duerksen (1980) find that trade and investment data suggest pollution-intensive industries relocate to other industrial countries instead of to less developed nations (LDCs). Leonard (1988) concludes that other factors such as labor training, infrastructure and political stability, as opposed to cost-savings from pollution regulations, play more important roles in the relocation decisions of multinational firms. However, the recent empirical study by Antweiler, Copeland and Taylor (2001) suggests that there is evidence to support the pollution haven hypothesis. Since the empirical study by Antweiler et al. (2001) is based on the predictions of a formal theoretical framework, the study provides more persuasive evidence to support the validity of the pollution haven hypothesis.

In the investigations of the "race to the bottom" in environmental protection laws, the evidence to support the hypothesis remains mixed. The "race to the bottom" concept, an offshoot of the pollution haven hypothesis, suggests that developing nations compete in lowering the stringency of environmental regulations in efforts to attract foreign investments from more developed nations. Developed countries are assumed to seek to relocation to pollution-intensive industries overseas to avoid stricter environmental standards at home. Sheldon (2006) concludes that a "race to the bottom" in environmental policy is unlikely for both small and large countries when standard analysis of optimal intervention applies. However, the paper suggests that the relaxation of the assumption of immobile factors implies the possibility that freer trade induces capital flight from more developed countries with stricter environmental regulations to less developed countries with weaker regulations. Sheldon (2006) asserts that studies which provides empirical evidence to support the pollution haven hypothesis lends some credence to the possibility of the race to the bottom in environmental policies amongst developed nations.

One reason frequently cited for inconclusive evidence in the study of trade-environment linkages is the lack of theoretical underpinnings to ground empirical predictions of the trade-environment relationships (Copeland and Taylor 2003). More recently, formal theoretical frameworks are advanced to provide basis for empirical hypotheses. In particular, the framework developed by Antweiler et al. (2001), based on the Heckscher-Ohlin type trade model, provides an explicit description of the environmental impact of inter-industry trade. An important contribution of the Antweiler et al. (2001) framework is the formal decomposition of the environmental impact of inter-industry trade into the scale, technique and composition effects. Although widely recognized, the scale, technique and composition effects originally postulated by Grossman and Krueger (1993, 1994), were never formally shown in earlier literature. Antweiler et. al (2001) use the predictions of the formal model to derive estimating equations for their empirical study, and find evidence to support the claim that trade is good for the environment. More recently, Taylor and Levinson (2004) present both theory and empirical evidence to "unmask" the pollution haven effect. The authors find evidence to support the hypothesis that industries that have the most increases in abatement costs experience the largest increases in net imports. Empirical findings based on theoretical predictions found in studies such as Antweiler et al. (2001) and Taylor and Levinson (2004) are more likely to provide persuasive evidence to validate trade-environment linkages.

While recent development in modeling trade-environment relationships contributes to providing theoretical underpinnings for empirical tests, most analyses are based on the traditional theory of trade. The Antweiler, Copeland and Taylor (2001) framework is based on the traditional framework of trade which assumes constant returns to scale and perfect competition. In contrast, theoretical frameworks that examine the impact of trade on the environment using "modern" trade theory are relatively scarce in literature. There is yet a formal framework to delineate the impact of intra-industry trade on environmental quality and to examine how structural parameters in a "new" trade model may unambiguously affect environmental quality. Furthermore, literature shows that most studies that are based on "new" trade focus on the issue of environmental policy rather than on describing the effects of international trade on domestic emissions levels. In particular, strategic behavior pertaining to the effect of domestic environmental regulation on foreign pollution levels is most typically examined. Markusen et al. (1995) use a two-region model to examine plant-level competition in environmental tax behavior in an imperfectly competitive market with increasing returns to scale. Their theoretical model shows that competition in environmental taxes may result in either driving the polluting firm out of the market when the disutility of pollution is high enough, or that the two regions will undercut each other's pollution tax rate when the disutility of pollution is low. Similarly, Haupt (2000) uses a strategic framework to examine the effect of stricter environmental policy on research and development when consumption is pollution-intensive. Haupt (2000) shows that when countries set environmental regulations in a non-cooperative setting, a country benefits from stricter policy abroad when it has high product standards at home.

To date, Gurztgen and Rauscher (2000) is the only study that proposes a general equilibrium analysis based on new trade theory. The authors develop a framework based on the Dixit-Stiglitz type model of monopolistic competition to examine the effects of domestic environmental regulation on trans-boundary pollution. The authors show that stricter domestic environmental standards may lead to lower emissions levels abroad. While Gurtzgen and Rauscher (2000) present a new trade-environment model, the study is similar to Markusen et. al (1995) and Haupt (2000) in that it focuses on the investigation of the effects of domestic policy on environmental quality abroad. In a subsequent study, Haupt (2006) analyzes the implications of non-cooperative environmental policy for local production externalities and concludes that the impact of international trade on the environment is ambiguous. The study extends previous investigations that examine the link between environmental policy and modern international trade.

A more recent empirical study by Cole and Elliot (2003) offers an investigation into the relationship between trade patterns and environmental regulations under both the traditional and the new theories of trade. The authors find that under the Heckscher-Ohlin-Vanek framework, there is no statistically significant evidence to support an empirical relationship between environmental regulations and trade patterns. On the other hand, under a monopolistic competition framework, the authors find statistically significant evidence to support a relationship between environmental regulation and intra- as well as inter-industry trade. The empirical equations in the Cole and Elliot (2003) study are based on Helpman's (1987) intra-industry trade model. One shortcoming of the analysis is that the authors do not offer a formal framework to describe the relationship between pollution level and trade variables. In short, the study does not have theoretical underpinnings in the environmental context.

A most recent theoretical environmental-trade framework based on new trade theory is advanced by Benarroch and Weder (2006). The authors build a two-country model of pollution which assumes monopolistic competition and increasing returns. The framework examines the effects of trade in intermediate products on pollution, output level and welfare under the conditions of endogenous tax and two pollution functions. The paper shows that international trade leads either to lower pollution in each country or lower pollution per unit output in one country. Additionally, the authors show that intra-industry trade leads countries to import the environmental quality of trading partners. The framework by Benarroch and Weder (2006) provides interesting insights into the effects of trade in intermediate goods on foreign emissions level. The analysis does not assume trade in final goods, the focus of analysis in this paper.

A review of trade-environment literature reveals the following: one, most investigations into the trade-environment relationships are based on the traditional theory of trade; two, literature that studies the link between the environment and "new" trade focus on the issue of environmental policy; three, there is no formal model that explicitly shows the impact of intra-industry trade on environmental quality in the closed and open economy contexts. In particular, the environmental impact of trade driven by economies of scale has not been explicitly differentiated from the environmental impact of trade driven by factor endowment differentials; and finally, the effects of an increase in the stringency of environmental policy on domestic local pollutant levels have not been formally shown for a model of monopolistic competition where trade involves the production of final goods.

The main objective of this paper is to analyze the environmental impact of trade in horizontally differentiated goods. I develop a model of trade and the environment by incorporating pollution externality into a "new" trade framework. The framework departs from the traditional trade-environment models in that it assumes increasing returns to scale and imperfect competition as opposed to constant returns to scale and perfect competition. Further, it departs from existing models under new trade theory by assuming pollutants are local rather than trans-boundary[1] and that trade is in final goods rather than in intermediate goods[2]. The framework developed in this paper shows that new trade theory leads to environmental impact that can be distinguished from the environmental impact of traditional trade theory. The current analysis derives a decomposition of the environmental impact of trade under new trade theory which generates "scale", "technique" and "selection" effects. This contrasts the results in Antweiler et. al (2001) which show that the decomposition of the environmental impact of trade under the traditional trade theory yields "scale", "technique" and "composition" effects. Hence, the current framework shows that the "selection" effect distinguishes the environmental impact of "new" trade from the "composition" effect, which is the environmental impact of "traditional" trade.

[1] Gurztgen and Rauscher (2000) developed a theoretical framework that examines how domestic environmental policy affects trans-boundary pollution level abroad.

[2] Benarroch and Weder (2006) built a model to investigate how intra-industry trade volume affects pollution emission from the production of intermediate goods, while the current analysis focuses on final goods.

Figure 2.1 and Figure 2.2 show the representations of the distinction between the environmental impacts of new trade as opposed to traditional trade. The differences in the theoretical assumptions between "traditional" and "new" trade theories are shown to lead to differences in the environmental effects of international trade. The impact of trade in homogenous goods or inter-industry trade, leads, in particular, to a composition effect. This is distinguished from the selection effect, one effect of trade in differentiated goods, or intra-industry trade. Figure 2.2 further shows that the combined effects of trade in both homogenous and differentiated goods yield four environmental effects, namely, the scale, technique, selection and composition effects.

2.3 The Model

I develop a model of pollution based on the neo-Chamberlinian-Krugman type model of monopolistic competition and trade. The Chamberlin economy describes a market structure characterized by the following main features: firms produce similar but differentiated-and-imperfectly substitutable goods; firms exercise market power; firms maximize profits; and finally, non-zero profits imply the entry and exit of firms. I extend the standard model of Krugman (1979) by incorporating pollution externality to examine the impact of trade on environmental quality.

The analysis in this section proceeds by characterizing the closed economy equilibrium followed by the open economy equilibrium.

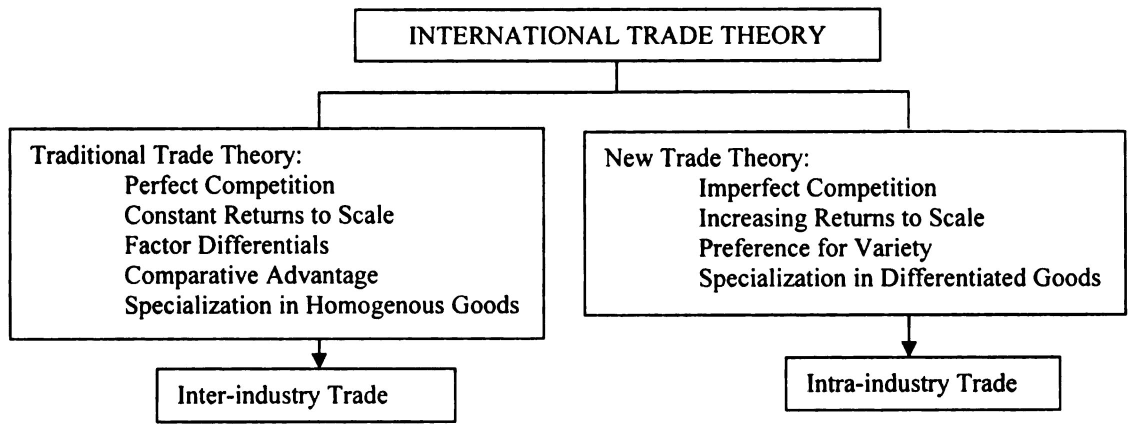

Figure 2.1: Inter-industry and Intra-industry Trade

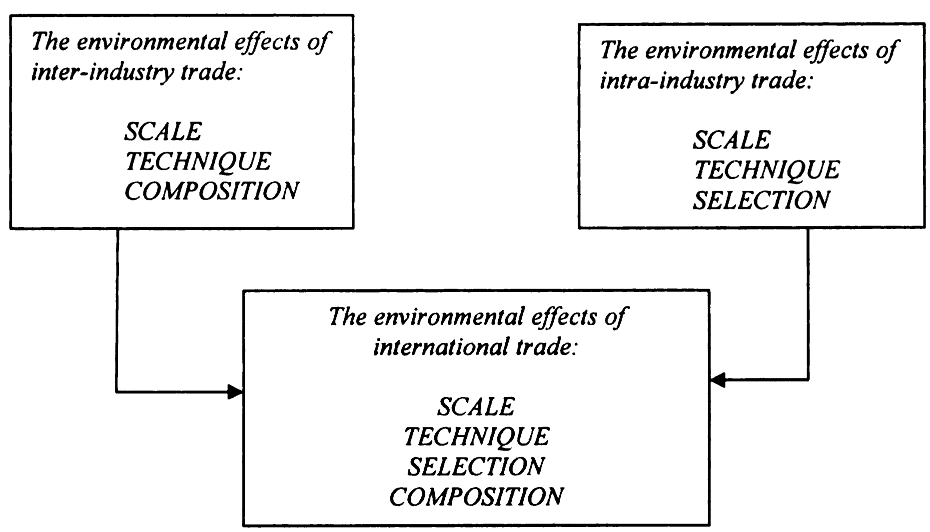

Figure 2.2: The Environmental Impact of International Trade

The economy is composed of consumers, firms, and a regulatory authority. Market structure is monopolistically competitive and production technology yields increasing returns to scale. Firms produce differentiated goods which generate pollution as a by-product, that is, pollution is a joint output of production. Firms have identical technologies and produce goods with a large number of potential product varieties. Due to the existence of economies of scale, each firm produces one type of product. Producers are identical except in the design of their products. Firms are able to differentiate their products without incurring additional costs. A large number of goods are produced such that there is negligible effect of the price of any one good on the demand of another; hence, one firm's behavior is independent of the other, that is, there is no strategic interdependence between firms.

Labor is the only factor of production that is inelastically supplied in a competitive labor market. Income in the economy comes from wage earnings. There are instantaneous adjustments to changes in variables, and there is perfect information. Finally, countries are identical in size, technology and preference, and there is zero transportation cost.

2.3.1 Demand

There is L number of consumers with identical preferences in the economy. The utility function takes the symmetric, additively separable form where love of variety is assumed with respect to the consumption of goods. Consumers do not derive utility from leisure. Each consumer receives positive utility from consuming c_i, the consumption of the *i*th good, but obtains negative utility (disutility) from pollution, z_i.

Products are horizontally differentiated and enter the utility function symmetrically[3]. Social damage from pollution comes from the disutility imposed on consumers. Consumers have no control over pollution. Therefore, consumers take

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[3] This is a standard assumption in the Krugman-type (1979/1980) model.

pollution as given. Thus, the consumer maximizes utility only with respect to the consumption of goods.

The utility function is as follows:

$$(2.1)\qquad U=\sum_{i=1}^{n} v(c_i)-\sum_{i=1}^{n} z_i \qquad\qquad v' > o,\quad v'' < 0,\quad u'>0$$

Let the representative consumer maximizes utility with respect to c_i subject to a budget constraint. Total income, y, is equal to wage, w, earned by the individual. Therefore the consumer's maximization problem is as follows:

$$\underset{\{c_i\}}{Max}\quad U=\sum_{i=1}^{n} v(c_i)-\sum_{i=1}^{n} z_i \qquad \text{subject to}\quad y=w$$

where $y=\sum_{i=1}^{n} p_i c_i$, and p_i denotes the price of the ith good.

Then, the first order condition for consumer utility maximization is:

$$(2.2)\qquad v'(c_i)=\lambda p_i \qquad\qquad i=1,\dots,n$$

where λ is the Lagrange multiplier and the marginal utility of income.

If the number of varieties is large such that the budget share of each variety is small, the impact of price on the marginal utility of income may be ignored. In that case, the effect of a change in price implies that the elasticity of demand for variety i is the following (see Krugman 1979):

$$(2.3)\qquad \eta_i=\frac{-dc_i}{dp_i}\cdot\frac{p_i}{c_i}=-\left(\frac{v'}{c_i v''}\right)>0$$

Following Krugman (1979), it is assumed that

$$(2.4)\qquad \frac{d\eta_i}{dc_i}<0$$

so that elasticity is increasing as we move up along the demand curve and consumption is falling.

2.3.2 Production

Firms have identical technologies where labor is a linear function of output and takes a particular functional form (Krugman 1979). There is increasing returns to scale that is internal to firms with positive initial fixed costs, constant marginal costs and thus declining average costs.

Output, q_i, is an increasing function of labor, l_i, such that:

(2.5) $$l_i = \alpha + \beta q_i \qquad \alpha > 0,\ \beta > 0$$

where α is the fixed cost of production.

Firms generate pollution jointly and symmetrically with the production of goods. For simplicity, assume pollution is generated in constant proportion to output production. Pollutants in the model are local in their manner of dispersion and are uniformly released into the environment. There is a regulatory authority which imposes emissions tax to internalize the negative pollution externality. In this paper, emissions tax is determined exogenously. In response to the implementation of environmental regulation, firms undertake emission abatement to avoid costly emission tax payments. In this model, resources for abatement are drawn from the output that firms produce. Therefore, firms allocate a portion of output towards abatement activity and allocate the remaining portion for goods consumption in the market.

Pollution emission, z_i, is the difference between potential pollution, z^F, and pollution abated, z^A. Emission per unit of output or emission intensity denoted e_i, is

z_i/q_i . Hence, the following equation specifies the relationship between emission and emission per unit output:

(2.6) $$z_i = e_i q_i$$

If each firm allocates q_i^a of units of output into abatement, then net output is:

(2.7) $$q_i^{net} = q_i(1-\theta_i)$$

where $\theta_i = q_i^a / q_i$ is the fraction of output allocated towards emission control.

Since individual consumers are the workers in goods production, total labor force in the economy is L. Then, supply of output is equal to demand given by the following relationship:

(2.8) $$(1-\theta_i)q_i = Lc_i \qquad 0 < \theta < 1$$

where $(1-\theta_i)$ is the fraction of output allocated towards consumption.

I specify a functional form for emission per unit to describe the relationship between pollution emission and output.[4] Emission per unit output or emission intensity, e_i, takes the following form:

(2.9)[5] $$e_i = (1-\theta_i)^{\delta} \qquad \text{where} \qquad 0 < \theta < 1$$

The parameter δ measures the responsiveness of a change in emission levels due to a change in the fraction of output allocated towards consumption. The elasticity is assumed

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[4] This approach allows for the explicit decomposition of the effects of intra-industry trade on environmental quality. It is also consistent with the approach of specifying a production technology in the Krugman (1979,1980) model.

[5] This particular functional form for emission per unit output differs from the emissions function of Antweiler, Copeland and Taylor (2001). The current form implies that emission release is released in increasing proportion relative to the production of dirty goods, consistent with pollution-intensive industries including the agricultural sector.

to be positive, which means that pollution is emitted in increasing proportion relative to the production of pollution-intensive or dirty goods. If δ is less than unitary, then this implies that the percentage change in emission is less than a percentage change in the fraction of output produced for consumption purpose. Generally, in pollution-intensive industries such as manufacturing and agriculture, pollution is emitted at an increasing rate with the increasing allocation of resources towards the production of goods. Therefore, for the functional form specified above, the assumption that δ is greater than unitary is reasonable and has a basis in the practical sense.

The pollution tax, τ, is taken to be high enough so that firms choose to undertake abatement activity. It is equal to zero if the regulatory authority does not impose any environmental regulation. In the absence of environmental regulation or zero emission tax rate, firms have no incentive to control pollution and the analysis reduces to a model without the considerations of abatement and pollution externality. The model without pollution would be identical to the Krugman (1979) model.

The profit function, denoted π, is the firm's revenue less labor cost, pollution taxes and abatement cost, is given by the following equation:

$$\pi_i = p_i(1-\theta_i)q_i - w\alpha - w\beta q_i - \tau z_i \tag{2.10}$$

Since all firms are identical, symmetry across firms implies that:

$$\left.\begin{aligned} p &= p_i \\ q &= q_i \\ \theta &= \theta_i \\ z &= z_i \end{aligned}\right\} \quad \text{for all } i$$

Henceforth, subscripts are suppressed.

2.3.3 Autarky Equilibrium

In the subsequent analysis, I refer the reader to Appendix A for detailed derivations of the results stated in this paper.

The first order conditions for profit maximization with respect to q implies:

$$p'(1-\theta)^2 q + p(1-\theta) - w\beta - \tau(1-\theta)^{\delta} = 0 \tag{2.11}$$

By simplification and by substitution for the elasticity of demand, the following equation is obtained:

$$p\left(1-\frac{1}{\eta}\right) = \frac{w\beta}{(1-\theta)} + \tau(1-\theta)^{\delta-1} \tag{2.12}$$

where η is the price elasticity of demand. Equation (2.12) shows marginal revenue, the term on the left hand side, is equal to marginal cost, the term on the right hand side. Marginal cost is the sum of (i) the marginal cost of production from the incremental use of labor normalized by the fraction of output/resource allocated towards goods' consumption and (ii) the marginal cost of emission per unit normalized by the consumption fraction.

The first order conditions for profit maximization with respect to θ is:

$$-qp'(1-\theta)q - qp + \tau\delta(1-\theta)^{\delta-1} q = 0 \tag{2.13}$$

Substituting for the elasticity of demand and simplifying, equation (2.13) can be rewritten as the following:

$$p\left(1-\frac{1}{\eta}\right) = \delta\tau(1-\theta)^{\delta-1} \tag{2.13'}$$

Equation (2.13') shows that marginal revenue is equal to the marginal cost of per unit emission that is normalized by per unit consumption and multiplied by the factor δ. The parameter δ is the elasticity of emission per unit with respect to per unit consumption. Equation (2.13') implies that the marginal revenue obtained from the incremental sale of consumption goods is equal to the opportunity cost of resources used to generate emission per unit. In this model, output is used as resources for two purposes, one, as consumption goods for the product market, and two, as resources in abating emissions. Equation (2.13') shows that the cost of foregone emissions multiplied by a factor of δ exactly equals the revenue that can be obtained were resources allocated away from abatement and into goods production for the purpose of consumption.

Second order conditions for profit maximizations are in Appendix A. Then, assuming an interior solution, the first order conditions can be solved for the fraction of output allocated towards abatement, θ, as:

(2.14)
$$\theta = 1 - \left(\frac{w\beta}{\tau(\delta - 1)} \right)^{\frac{1}{\delta}}$$

Equation (2.14) shows that the fraction of output allocated towards abatement is a function of wage rate, emission tax rate and the predetermined factors or parameters. It is decreasing in wage w, the labor coefficient β, and in the marginal cost of goods production, $w\beta$. Consistent with theory, the fraction of output allocated towards abatement is increasing in emission tax rate, τ. This means that a more stringent environmental policy leads to higher level of abatement activity. The equation also shows that the abatement fraction of output is increasing in the elasticity of per unit emissions with respect to per unit consumption, δ. The more elastic emission intensity is to a change in the allocation of output towards consumption, the greater the allocation of output towards abatement. This implies that higher emission intensity from an expansion of the scale of production necessarily leads to higher abatement levels as the firm attempts to exert greater control over the production of emission. This is consistent with the abatement theory that firms choose to reduce emission levels to avoid higher emission tax cost.

Since the fraction of output used for abatement is a value that is between zero and one, equation (2.14) implies the following:

$$0 \leq \left(\frac{w\beta}{\tau(\delta - 1)} \right)^{\frac{1}{\delta}} \leq 1 \tag{2.15}$$

Equation (2.15) indicates that for the condition to hold and be meaningful, it is required that $(\delta - 1) \neq 0$, that is, $\delta > 1$. Then, as mentioned in the foregoing, $\delta > 1$ implies that pollution is emitted at an increasing rate when greater amount of resources are allocated towards the production of dirty goods.

By substitution of equation (2.14) into equation (2.9), emission per unit output can be written as (see Appendix A):

$$e = \left(\frac{w\beta}{\tau(\delta - 1)} \right) \tag{2.16}$$

Equation (2.16) shows emission intensity decreases with more stringent environmental policy, but increases with an increase in the marginal cost of production of output. A more stringent policy implies that firms strive to reduce emissions level by increasing abatement levels. This results in lower emission intensity per unit output. On the other hand, higher marginal cost of production implies that there is an expansion of production which leads to an increase in emission intensity.

The equilibrium pricing rule is obtained by substituting equation (2.14) into (2.12), and is given as the following:

$$p\left(1-\frac{1}{\eta}\right)=(w\beta)\left(\frac{w\beta}{\tau(\delta-1)}\right)^{-\frac{1}{\delta}}\left(\frac{\delta}{(\delta-1)}\right) \tag{2.17}$$

Equation (2.17) shows that the pricing rule is a function of the elasticity of demand for variety η, the emission elasticity parameter δ, wage rate w, the labor productivity coefficient β, and the emission tax τ. Unlike the pricing equation in a model without pollution (see Krugman 1979), the pricing equation in the current model indicates that price is a function of emission tax rate. The imposition of an emissions tax yields an equilibrium price that is multiplied by a factor of the emissions tax rate and the elasticity of emission intensity. Hence, in the model with pollution externality, product price is determined not only by the marginal cost of production, but it is also determined by the emission tax rate and the emission intensity of production.

By substituting for the value of θ and e, I rewrite equation (2.17) as:

$$p=\left(1-\frac{1}{\eta}\right)^{-1}(w\beta)e^{-\frac{1}{\delta}}\left(\frac{\delta}{(\delta-1)}\right) \tag{2.17'}$$

Equation (2.17') indicates that given the emission elasticity parameter and the elasticity of demand for variety, the pricing rule is a function of emissions per unit output such that it is decreasing in emission intensity. This implies the higher the emissions intensity, the lower the price of market goods. One explanation for the lower price is that there is a trade-off between emission control and the allocation of goods for consumption. Greater emission intensity means there is less abatement, which in turn implies that there is greater allocation of output for the purpose of consumption. Therefore, holding every other factor equal, a greater supply of goods induces a lower product price in the market.

Equation (2.17) is one of the two equilibrium conditions that determine the equilibrium level of consumption of product varieties and the price level for the firm. I designate equation (2.17) as the PE line. This curve is similar to the PP line in Kugman (1979), but in the model of pollution, the PE line is a function of emission tax rate. I rewrite the PE line as:

(2.18)
$$\frac{p}{w}=\left(1-\frac{1}{\eta}\right)^{-1}\left(\frac{w\beta}{\tau(\delta-1)}\right)^{-\frac{1}{\delta}}\beta\left(\frac{\delta}{(\delta-1)}\right)$$
or
$$\frac{p}{w}=\left(1-\frac{1}{\eta}\right)^{-1}\left(\frac{\tau}{w}\right)^{\frac{1}{\delta}}\delta\left(\frac{\beta}{(\delta-1)}\right)^{\frac{\delta-1}{\delta}}$$

The other equilibrium condition is the zero profit condition. Free entry with positive profits requires that firms earn zero profit in the long run. In the current model, the zero profit condition is given by the following equation:

(2.19)
$$p(1-\theta)q-w\alpha-w\beta q-\tau(1-\theta)^{\delta}q=0$$

Divide equation (2.19) by net output, $(1-\theta)q$, and the wage rate, w, and then substitute total consumption (Lc) for quantity supplied. By equation (2.14) and rearranging, the following equation is obtained:

(2.20)
$$\frac{p}{w}=\left(\frac{\tau}{w}\right)^{\frac{1}{\delta}}\left(\frac{\alpha}{Lc}\left(\frac{\beta}{(\delta-1)}\right)^{-\frac{1}{\delta}}+\delta\left(\frac{\beta}{(\delta-1)}\right)^{\frac{\delta-1}{\delta}}\right)$$

Equation (2.20) is the equilibrium condition where price equals the average of the sum of labor cost and emission cost. Designate this line as the ZE line.

Equations (2.18) and (2.20) form two equations that can be solved for the two unknowns, $\frac{p}{w}$, and consumption, c, or alternatively, to solve for quantity of output, q. In this model of pollution externality, I solve for the quantity of output instead of consumption for the reason that output is the more relevant variable in analyzing changes in emission levels[6].

Then, given an emission tax rate and fixed parameters in the system, I can graph equations (2.18) and (2.20) in the price and output space; the equations are designated as the PE and the ZE curves respectively. This is shown in Figure 2.3.

Following Krugman (1979), I assume that $d\eta_i/dc_i < 0$. Therefore, this means that in a model of pollution, the PE line that represents equation (2.18) is shown to be upward sloping, and the ZE line that represents equation (2.20) is downward sloping (see Appendix A for proofs).

The relationship between the PE and ZE lines with respect to output level is shown in the following equations (2.21) and (2.22) (see Appendix A for details). Taking the total differentiation of the PE line with respect to output yields the following equation:

$$\text{(2.21)} \qquad \frac{d(PE)}{dq} = \left\{ -\left(1-(\eta(c))^{-1}\right)^{-2} (\eta(c))^{-2} \frac{\partial \eta}{\partial c} \cdot \frac{\partial c}{\partial q} \right\}$$

Equation (2.21) shows the PE line is upward sloping since $\frac{\partial n}{\partial c} < 0$ and $\frac{\partial c}{\partial q} > 0$.

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6 This contrasts with the Krugman (1979) trade model which solved for consumption level.

Taking the total differentiation of the ZE line with respect to output yields the following:

(2.22) $$\frac{d(ZE)}{dq} = -\alpha q^{-2} \mathrm{M}^{-1}$$

where $$\mathrm{M} = \left(\frac{w\beta}{\tau(\delta-1)} \right)^{\frac{1}{\delta}} .$$

Equation (2.22) shows the ZE line is downward sloping.

Figure 2.3 shows the diagrammatic representation of the relationship between the PE and ZE lines and the levels of output and price.

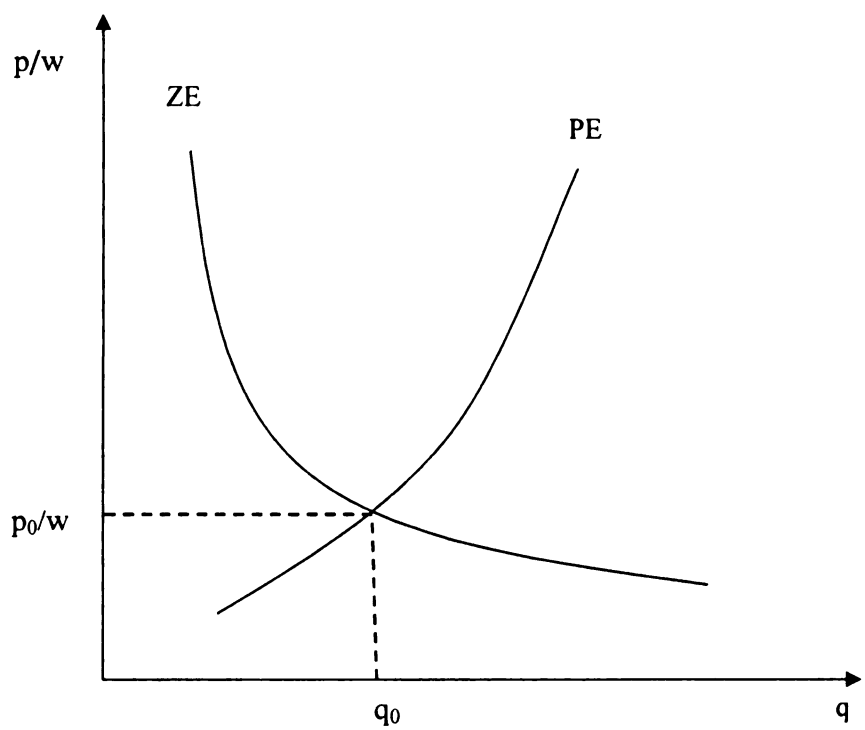

Figure 2.3: The PE line and the ZE line.

Using the full employment equation, I solve for the number of product varieties, n. Then, by equations (2.8) and (2.14), and assuming symmetry, the following results is obtained:

(2.23)

$$L=\sum_{i=1}^{n}(\alpha+\beta q_i)=n(\alpha+\beta q)$$

or

$$L=n\left(\alpha+\frac{\beta Lc}{(1-\theta)}\right)=n\left(\alpha+\frac{\beta Lc}{\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}}\right)$$

Solve for n such that:

(2.23')

$$n=\frac{L}{(\alpha+\beta q)},\quad n=\frac{1}{\alpha L^{-1}+\beta c\left(\frac{w\beta}{\tau(\delta-1)}\right)^{-\frac{1}{\delta}}}$$

Equation (2.23') shows the number of product varieties is a function of total labor, consumption level, the wage rate, emission tax rate and other predetermined variables. For a given level of consumption, an increase in the labor force increases the number of product varieties. On the other hand, an increase in emission tax rate decreases the number of product varieties.

2.3.4 Decomposition of Impact: Scale, Technique and Selection Effects

In this subsection, I show the decomposition of the impact of pollution-intensive production on total emission.

Use equation (2.6) to obtain the following:

(2.24) $$z_i = e_i q_i \Rightarrow \sum_{i=1}^{n} z_i = \sum_{i=1}^{n} e_i q_i = \sum_{i=1}^{n} e_i \left(Lc_i / (1-\theta_i) \right)$$

Note that in the closed economy, total labor L, is fixed, and with symmetry across firms, these imply:

(2.25) $$\begin{aligned} &\sum_{i=1}^{n} z_i = \sum_{i}^{n} e_i q_i \Rightarrow nz = n \cdot e \cdot q \\ &and \\ &\sum_{i=1}^{n} z_i = L \sum_{i}^{n} e_i c_i / (1-\theta_i) \Rightarrow nz = L \cdot n \cdot ec/(1-\theta) \end{aligned}$$

Let $nz = Z$ (total pollution), and rewrite equation (2.25) in differential form (hats denote percent change) to obtain the following result[7]:

(2.26) $$\begin{aligned} &\hat{Z} = \hat{n} + \hat{e} + \hat{q} \\ &or \\ &\hat{Z} = \hat{n} + \hat{L} + \hat{c} + \hat{e} - \widehat{(1-\theta)} \end{aligned}$$

Thus, equation (2.26) shows that the impact of economic factors on pollution can be decomposed into the *selection*, *scale,* and *technique effects* in the following way:

(2.26.1) Selection effect, $\hat{n}$

(2.26.2) Scale effect, $\hat{S} = \hat{q}$ or $\hat{S} = \hat{L} + \hat{c} - \widehat{(1-\theta)}$

(2.26.3) Technique effect, $\hat{e}$

Hence, in a model of monopolistic competition and increasing returns, the impact of the production of dirty goods generates three types of effects, namely the scale, technique and selection effects.

7 See Appendix A for more detailed derivation.

Equations (2.26.1), (2.26.2) and (2.26.3) show the environmental effects of pollution-intensive production, holding other determinants constant. I describe the scale, technique and selection effects as follows.

The scale effect refers to the change in emissions level due to a change in the scale of the economy, holding other factors constant. The technique effect is the change in emissions level due to a change in emission intensity, holding every other factor equal. The selection effect is the change in emissions level due to a change in the number of product varieties or in the number of firms, holding other factors constant.

Thus, equation (2.26) shows that growth in total emissions level depends on the growth of the scale of the economy, the growth in emission intensity of production, and the growth in the number of firms, or equivalently, in the number of product varieties.

The current model distinguishes the environmental impact of trade driven by the demand aspect of the economy from the environmental impact of trade driven by the supply or production aspect of the economy. While the impact of pollution-intensive production in a perfectly competitive market can be decomposed into scale, technique and composition effects (Antweiler et al. 2001), equation (2.26) shows that the impact of dirty production in a monopolistically competitive market can be decomposed into scale, technique and selection effects. In other words, the difference between a pollution model based on new trade theory from one that is based on traditional trade theory is that the former yields a selection effect while the latter yields a composition effect.

Further, equation (2.26) implies that under new trade theory, the environmental impact of trade can be broken down into finer structural decomposition. Note that under monopolistic competition, growth of the scale effect can be further decomposed into the effects of growth in the factor of production, labor, L, growth in the demand or consumption of products, c, and growth in the fraction of output allocated towards consumption and exports, $(1-\theta)$. This differentiates the scale effect in the new trade model from the scale effect as defined in the traditional model in literature.

While the new trade framework offers a more detailed decomposition, it is noted that in empirical investigations, difficulty may arise in differentiating the effects of "new" trade variables from "traditional" trade variables in the data. To facilitate the empirical measurements of variables, I condense the intra-industry trade decomposition of the scale and technique effects to parallel the conventional decomposition in inter-industry trade, hence establishing a link between the new trade theory and traditional trade theory in the environmental context. I also note that although the parallel decomposition is desirable, it is not necessary. The environmental impact of trade under new trade theory can be decomposed in a defined representation that can be explicitly separated from the environmental decomposition under the traditional trade theory.

In addition, I make a distinction between the scale, technique and selection effects in autarky and the "trade-induced" scale, technique and selection effects in the open economy. The scale, technique and selection effects in autarky are driven by changes in the structural factors in the closed economy, while the trade-induced scale, technique and selection effects are driven by changes in structural factors caused by the opening of trade.

Finally, equation (2.26) indicates that the decomposition of the impact of dirty production shows that the total impact of trade on emission level is the sum of the magnitude of each of the scale, technique and selection effects. The effects of scale, technique and selection relative to each other will determine whether the joint production of pollution will raise or lower aggregate emission in the closed economy or autarky.

2.4 Comparative Statics Effects of a Change in Environmental Policy

In this section, I analyze the implications of a change in the stringency of environmental policy on the main variables of interest in the economy. I present the scale, selection and technique effects as defined by the relationship between emissions tax and the level of abatement, emission intensity, price level, level of output, and the number of firms (or product varieties).

LEMMA 2.1: *Consider an economy described by monopolistic competition and increasing returns in the production of dirty goods. Then, an increase in the stringency of environmental policy raises the firm's level of emission abatement, while a reduction in the stringency of environmental policy lowers it.*

PROOF:

Equation (2.14) shows that the fraction of output allocated towards abatement is a function of predetermined factors and the exogenously determined emissions tax. Taking the simple derivative of equation (2.14) with respect to emission tax rate yields the following result:

$$\frac{\partial \theta}{\partial \tau} = (\delta\tau)^{-1}\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}} > 0 \tag{2.27}$$

Therefore, equation (2. 27) shows that an increase in emissions tax rate or environmental policy increases the level of abatement.

PROPOSITION 2.1: *An increase in the stringency of environmental policy lowers the firm's emission intensity while a decrease in the stringency of environmental policy raises it. This is the policy-induced technique effect.*

PROOF:

Equation (2.16) shows that emission intensity is a function of parameters and the emissions tax. Take the derivative of equation (2.16) with respect to emission tax rate to obtain the following result:

(2.28) $$\frac{\partial e}{\partial \tau} = -\tau^{-1}\left(\frac{w\beta}{\tau(\delta - 1)}\right) < 0$$

Equation (2.28) indicates that an increase in emission tax rate reduces emission per unit output. This result can be explained as follows. A more stringent environmental policy leads the firm to lower emission intensity for the following reason: an increase in emission tax rate implies that there is a trade-off between using resources for the production of consumption goods and using resources for abating emissions. When a higher emission tax rate is imposed, the production of consumption goods becomes a costlier activity. Higher tax payments contribute to increasing the cost of production. To mitigate the cost of environmental compliance, the firm reallocates output away from the production of goods for consumption and allocates it into abating emission. As the firm undertakes a greater level of abatement, it lowers the emission intensity per unit output. On the other hand, a reduction in the stringency of environmental policy will have the opposite effect. Lower emission tax rate means emissions abatement becomes a less costly activity. This provides incentive for the firm to reallocate resources into supplying goods for consumption to increase revenue. This implies an expansion of the scale of production. Consequently, less abatement which led to expanded production leads, in turn, to an increase in emission intensity.

LEMMA 2.2: *In an economy where the production technology is increasing returns to scale and market structure is monopolistically competitive, an increase in the stringency of environmental policy leads to a decrease in the consumption of product varieties.*

PROOF:

Comparative statics effect of a change in emission tax rate on the level of consumption is given by the following equation (see Appendix A for detail):

$$\text{(2.29)} \qquad \frac{dc}{d\tau} = \frac{-\left\{\left(1-(\eta)^{-1}\right)^{-1}\frac{1}{\delta}\tau^{\frac{1}{\delta}-1}\varpi^{-1}\mathrm{B}\right\}}{\left\{\alpha L^{-1}c^{-2}-\left(1-(\eta)^{-1}\right)^{-2}(\eta)^{-2}\frac{\partial\eta}{\partial c}\tau^{\frac{1}{\delta}}\varpi^{-1}\mathrm{B}\right\}} < 0$$

where $\frac{\partial\eta}{\partial c} < 0$, $\varpi = \left(\frac{w\beta}{(\delta-1)}\right)^{\frac{1}{\delta}}$ *and* $\mathrm{B} = \beta\left(\frac{\delta}{(\delta-1)}\right)$.

Equation (2.29) shows that the numerator on the left hand side is negative while the denominator is positive. Thus, there is a negative relationship between the consumption of product varieties and the emission tax rate. An increase in emission tax rate leads to a decrease in the level of consumption.

Intuitively, an increase in emission tax rate leads to the following effects. One, a higher emission tax rate implies an increase in emission tax payments which increases the total costs of production. Firms respond to the increase in costs by raising product price to reflect the increase in resource costs of producing goods for consumption. Consequently, consumers respond to the increase in higher price levels by reducing the quantity demanded of each product variety. Two, when environmental policy is tightened, firms comply with stricter regulation by increasing abatement to reduce emission intensity. Since output is used for both consumption and abatement purposes, an increase in emission tax rate implies a trade-off between using output for consumption and using it for abatement. Increased abatement leads to a reduction of output available for the goods market, thus leading to a decrease in the level of consumption.

PROPOSITION 2.2: *In an economy where the production of dirty differentiated goods entails economies of scale, an increase in the stringency of environmental policy leads to a contraction in the firm's scale of production, while a decrease in environmental stringency leads to an expansion of the scale of production. This is the policy-induced scale effect.*

PROOF:

Comparative static effect of a change in the emission tax rate on the quantity of output is given by the following equation (see Appendix A for detail):

(2.30) $$\frac{dq}{d\tau} = -D^{-1}\left(1-\eta^{-1}\right)^{-2}\eta^{-1}\tau^{-1}\delta^{-1}pw^{-2}\frac{\partial\eta}{\partial c}\frac{c}{\eta} < 0$$

Equation (2.30) shows that an increase in the emission tax rate leads to a contraction in the scale of production. The effect of an increase in the stringency of environmental policy is twofold. One, the firm faces a higher cost of production due to increased tax payments. Two, the firm complies with stricter environmental regulation by increasing abatement levels. Both effects lead to higher production costs which shift the firm's marginal cost curve to the left. The firm cuts down on production which leads to a decrease in the supply of output.

PROPOSITION 2.3: *In an economy where the production of dirty differentiated goods entails economies of scale, an increase in the stringency of environmental policy raises the price level, while a decrease in environmental stringency lowers the price level.*

PROOF:

Comparative statics effect of a change in emission tax rate on the price level is given by the following equation (see Appendix A for detail):

(2.31) $$\frac{dp}{d\tau} = D^{-1}\tau^{\frac{2}{\delta}}\varpi^{-2}\mathrm{B}\delta^{-1}\tau^{-1}q^{-1}\left[\mathrm{B}\eta^{-1}\frac{\partial\eta}{\partial c}\frac{c}{\eta} - \alpha q^{-1}\left(1-\eta^{-1}\right)^{-1}\right] > 0$$

where $$\varpi = \left(\frac{w\beta}{(\delta-1)}\right)^{\frac{1}{\delta}} \quad and \quad \mathrm{B} = \beta\left(\frac{\delta}{(\delta-1)}\right)$$

Equation (2.31) shows that the term on the right hand side is positive, which indicates that a positive change in emission tax rate leads to positive change in the price level and a negative change in emission tax rate leads to a negative change in the price level.

A positive effect of a change in the emission tax rate on the price of a product variety is consistent with the prediction of theory. When a higher emission tax rate is imposed, the firm increases abatement activity to mitigate the rising cost of compliance. Increased abatement entails higher production cost, which comes from two sources: one, from increased emission tax payments, and two, from increased resource-cost in controlling emission level. The latter implies that the firm's allocation of output towards abatement activity increases and its allocation of output for consumption goods declines. Consequently, the firm raises product price to reflect the opportunity cost of meeting higher environmental standards.

PROPOSITION 2.4: *In an economy characterized by increasing returns and monopolistic competition, an increase in the stringency of environmental policy leads to an increase in the number of firms, while a decrease in the stringency of policy leads to a decrease in the number of firms. This is the policy-induced selection effect.*

PROOF:

Comparative statics effects of a change in emission tax rate on the number of firms and the output level are given by the following equations (see Appendix A for details):

(2.32) $$\frac{dn}{d\tau} = -\left(\frac{L\beta}{(\alpha+\beta q)^2}\right)\frac{dq}{d\tau}$$

Equation (2.32) shows that the effect of a change in emission tax rate on the number of firms depends on the effect of a change in emission tax rate on the output level. Since the effect of a change in environmental policy on the output level is negative, then the effect of the change in policy on the number of firms is positive. In other words, the effect of a change in environmental policy on the number for firms is the opposite of the effect of a change in environmental policy on the output level.

The intuition of the overall impact of an increase in emission tax rate on emission intensity, the price level, the scale of production and the number of firms, is as follows. When emission tax rate increases, firms raise product prices to offset the increase in production cost due to higher tax payments. As price level rises, quantity demanded decreases such that the firm's revenue falls. In addition, a higher emission tax rate implies the firm will raise abatement activities to comply with stricter environmental policy. Consequently, firms allocate a smaller fraction of output for consumption purposes. This reduces the quantity of output supplied to the market, thus further raising the price levels. As product price increases, new firms enter the market motivated by high price levels. Hence, the number of firms in the industry rises.

Since the amount of labor is fixed, there is tight supply in the factor market. Existing firms are not able to hire enough labor to take advantage of economies of scale, as they attempt to lower the price of products to meet falling demand and compete with newer firms. The increase in production costs, the decrease in revenues and the increase in competition force the firm to move up along its average cost curves, such that the scale of production contracts as per unit cost increases. Therefore, higher emission tax rate has led to lower output levels. For the economy as a whole, higher emission tax rate has led to higher price levels and an increase in the number of firms, or equivalently, in the number of product varieties available for consumption.

Figure 2.4 depicts the effect of an increase in the stringency of environmental policy on the price level and output level for the firm. An increase in emission tax rate shifts the PE line upward and to the left to PE', and shifts the ZE line upward and to the right to ZE'. The price level has risen from p_0/w to p_1/w. In this case, firms are not able

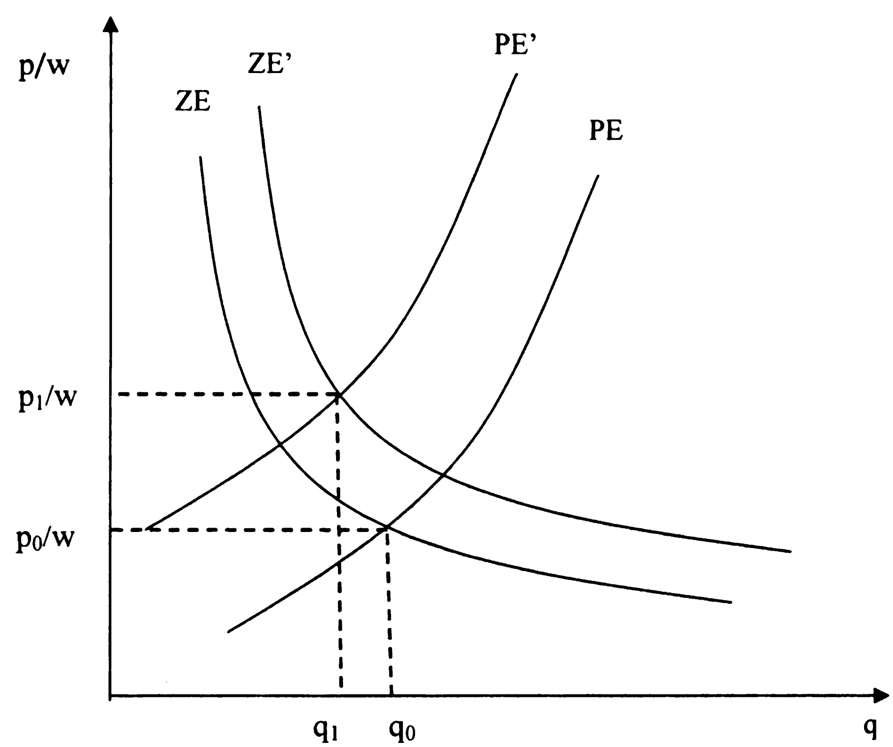

Figure 2.4 shows that an increase in the stringency of environmental policy shifts the PE curve upward and to the left to PE' and it shifts the ZE curve upward and to the right to ZE' such that the price level rises and the output level falls.

to take advantage of economies of scale to overcome the offsetting effect of an increase in price. Consequently, the firm cuts down on production, and the quantity of output decreases from q_0 to q_1.

PROPOSITION 2.5: *Consider an economy where market structure is monopolistically competitive, production is increasing returns to scale, and firms undertake abatement in the pollution-intensive production of differentiated goods. Then, the total effect of a change in the stringency of environmental policy may increase, or decrease, or leave unchanged total emissions level in the economy.*

PROOF:

Totally differentiate equation (2.24) and take its derivative with respect to emission tax rate to obtain the following:

(2.33) $$\frac{dZ}{d\tau} = (eq)\frac{dn}{d\tau} + (nq)\frac{de}{d\tau} + (ne)\frac{dq}{d\tau}$$

Equation (2.33) shows that the change in total emission due to a change in the emission tax rate is the sum of the policy-induced changes in the emission intensity, $\frac{de}{d\tau}$, the number of firms, $\frac{dn}{d\tau}$, and the scale of production, $\frac{dq}{d\tau}$, which are correspondingly the policy-induced technique, selection and scale effects, respectively. An increase in emission tax rate is shown to lead to the following three effects: (i) it raises the firm's abatement level and lowers the emission intensity; (ii) it increases the number of firms in the industry; and (iii) it leads to a contraction in the firm's scale of production.

Therefore, the total impact of the policy-induced change in overall emission is the sum of the policy-induced decrease in emission intensity, increase in the number of firms and contraction in the scale of production.

Note that equation (2.28) shows that the policy-induced technique effect is negatively related to the level of emissions. Equation (2.30) shows that the policy-induced scale effect is negatively related to emissions level. On the other hand, equation (2.32) shows that the policy-induced selection effect is positively related to emissions level. Thus, the aggregate impact of a change in environmental policy on total emission is contingent on the direction and magnitudes of the policy-induced technique, scale and selection effects. In other words, the total impact may be positive, negative, or unchanged, depending on whether the negative effects of technique and scale are larger or smaller than, or equal to the positive effect of selection.

PROPOSITION 2.6: *Consider an economy where market structure is monopolistically competitive, production is increasing returns to scale, and firms undertake abatement in the pollution-intensive production of differentiated goods. Then, while the total effect of an increase in the stringency of environmental policy may increase, or decrease, or leave unchanged the total aggregate emission in the economy, the effect of an increase in the stringency of environmental on the price level is to raise it.*

PROOF:

Equation (2.31) shows that an increase in emissions tax rate increases the product price, while equation (2.33) shows it may increase, decrease or have no effect on total emissions level.

Proposition 2.6 presents an interesting result of the effects of stricter environmental policy. The implementation of more stringent policy has ambiguous effects on environmental quality because it depends on the aggregate or sum effects of the three policy-induced scale, technique and selection effects. Theory cannot provide a definite determination on how more stringent policy can ultimately affect environmental quality. On the other hand, the cost of a higher emissions tax rate is unambiguous: it increases product price and decreases the level of consumption of product varieties (see Lemma 2.2). Therefore, the net effect of tightening regulation may not have the desired benefit as intended: it imposes costs on consumption and production, and generates uncertainty with respect to the primary objective of improving environmental quality.

Table A.2 (see Appendix A) summarizes the comparative statics effects of a change in environmental policy on the variables of interest: abatement level, emission intensity, price level, output level, the firm's emission level, the number of firms (or product varieties) and the total emission in the economy.

2.5 Trade and Pollution

In this section, I consider the environmental effects of trade for two countries with identical preferences, technologies and factor endowments. Note that in a Heckscher-Ohlin world, there is no reason to trade when countries are identical in terms of factor abundance. In the current model, trade is driven by existing economies of scale in the production of differentiated products; products are valued by consumers with love-for-variety preferences. Since the goods are pollution-intensive, the opening of trade affects emissions level in the domestic economy.

In the following analysis, the relationship between the price level and the consumption level of product variety is used to describe the impact of trade in differentiated goods on environmental quality.

Theoretically, in the integrated world economy, openness to trade influences L, the size of labor (Krugman 1979, 1980). While the impact of trade on the economy is captured by the change in the level of consumption through a shift in the zero-profit curve, in contrast, the impact of free trade on the quantity of output is not directly obtained through a shift in the zero-profit curve, when L changes. The effect of trade on the labor supply, L, can be seen in the following way.

Rewrite the ZE curve as the ZZ line (see Appendix A for detail):

(2.35) $$ZZ: \quad \frac{p}{w} = L^{-1}\frac{\alpha}{c} + \varpi^{-1}\mathrm{B}$$

where

$$\varpi = \left(\frac{(w\beta)}{\tau(\delta-1)}\right)^{\frac{1}{\delta}} \quad and \quad \mathrm{B} = \beta\left(\frac{\delta}{(\delta-1)}\right)$$

Then, the slope of the ZZ line (with respect to consumption) is:

$$\frac{\left(\frac{p}{w}\right)}{dc} = -c^{-2}\frac{\alpha}{L} < 0$$

Thus the ZZ curve is downward sloping.

Then, taking the derivative of the ZZ line with respect to fixed labor, L:

$$\frac{\partial(ZZ)}{\partial L} = \frac{\partial\left(\frac{p}{w}\right)}{\partial L} = -L^{-2}\frac{\alpha}{c} < 0$$

Therefore, a change in the labor population shifts the ZZ curve in a negative direction.

Figure 2.5 shows the ZZ and PE curves in the price-consumption space. When two identical countries trade in differentiated, pollution-intensive goods, it is as if there is an increase in labor supply.

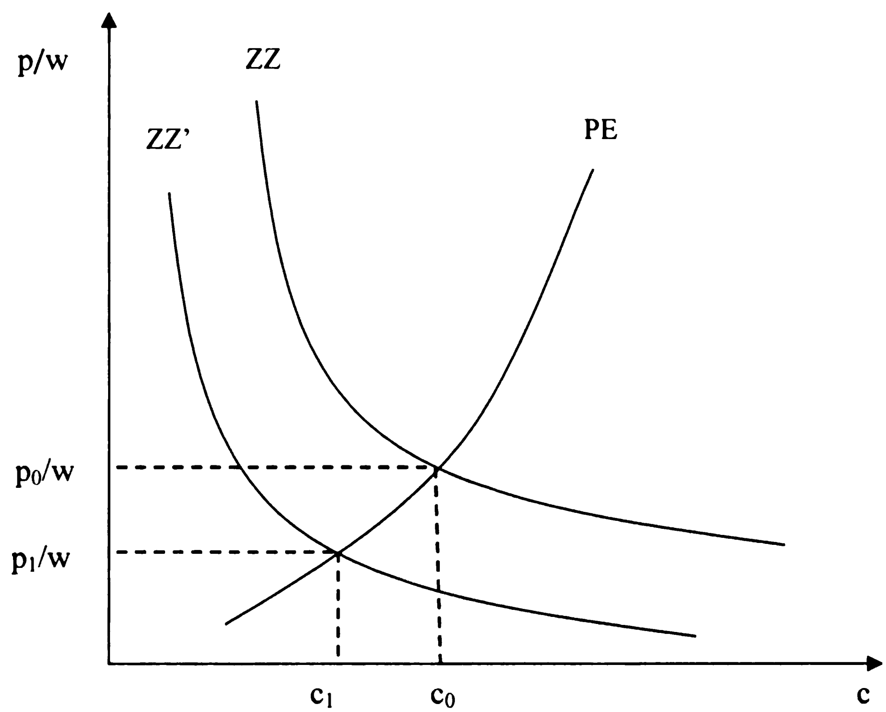

Figure 2.5: With the opening of trade, it is as if there is an increase in the amount of labor available for production. Consequently, the ZZ curve shifts down and to the left, where quantity of consumption decreases from c_0 to c_1 and the price level falls from p_0/w to p_1/w. Thus, the gains from trade are achieved through two sources: one, from the decline in the price level, and two, from the increase in the number of varieties due to imports. However, since goods are dirty, intra-industry trade affects the emissions level in the economy.

The increase in labor supply shifts the ZZ curve downward and to the left to yield both a fall in the price level and a fall in the consumption of a variety of goods. The fall in consumption leads to the exit of firms that earn negative profit as they cannot compete with foreign firms or products. Firms that survive in the open economy expand their production by taking advantage of economies of scale and hiring excess labor in the factor market. As price level falls from p_0/w to p_1/w, there is a gain in real income, which contributes to an increased level of economic welfare.

Hence, the effects of trade on the structural factors of the economy with pollution are similar to the effects of trade in an economy without pollution. There is, however, a distinguishing difference between the impacts of trade on the two economies. In a model where dirty goods are produced, openness to trade further influences structural factors which lead to changes in the environmental aspect of the economy.

Trade in differentiated but dirty goods leads to three environmental effects. First, when countries engage in intra-industry trade of dirty goods, trade acts as if there is an increase the supply of labor. Thus, open trade implies there is a greater number of product varieties available for consumption. Imports and the competition from abroad cause some domestic firms to exit the industry. Consequently, the number of firms in the open economy falls. Holding everything else constant, a smaller number of firms generate less emission into the environment. This is the trade-induced selection effect. Second, surviving firms increase output as they expand production to take advantage of economies of scale. All other factors equal, a larger scale of production generates a greater level of pollution emission. This is the trade-induced scale effect. Furthermore, as output level rises with the opening of trade, the price level falls, and real income rises.

Third, higher income level promotes stricter environmental policy since environmental quality is a normal good. An imposition of a higher emission tax rate leads to greater emission control, and thus lower emission intensity. This is the trade-induced technique effect.

Therefore, when production entails a pollution externality, intra-industry trade generates the following environmental effects. Holding other factors constant: one, the trade-induced environmental scale effect is due to the expansion of production and economies of scale; two, the trade-induced environmental selection effect is due to the entry and exit of firms due to increased competition from abroad; and three, the trade-induced environmental technique effect is due to a fall in emission intensity when environmental regulations become more stringent as income level rises.

The foregoing analysis of the impact of trade on the environment can be stated more formally as follows:

PROPOSITION 2.7: *Consider two identical economies engaged in intra-industry trade. Then, under the conditions of monopolistic competition market structure and increasing returns to scale technology, free trade implies there are three trade-induced environmental effects: a positive scale effect, a negative selection effect, and a negative technique effect.*

PROPOSITION 2.8: *The impact of trade on total emission is the sum of the trade-induced scale, selection, and technique effects. The magnitude and direction of each effect determine the overall impact of intra-industry trade on environmental quality.*

PROOF:

From equation (2.26):

(2.26) $$\hat{Z} = \hat{n} + \hat{e} + \hat{q}$$

Equation (2.26) shows that the environmental impact of pollution intensive production are as follows: (i) it can be decomposed into the selection, technique and scale effects, and (ii) it is the sum of the scale, selection and technique effects.

Therefore, if international trade expands the firm's production of differentiated goods, while the total number of firms has fallen and emission intensity is unchanged, then the trade-induced scale effect may or may not offset the effects of trade-induced selection and technique. In this case, total emissions may rise or fall.

In the case where international trade and scale economies allow the firm to expand production to the extent that the trade-induced scale effect generates an overwhelming increase in emissions level, then total domestic emissions may rise even if there are fewer firms in the economy. On the other hand, if trade and economies of scale allow the firm to expand production but only to a small extent, such that a reduction in the number of firms, the trade-induced selection effect, is enough to offset the increase in the scale effect, then total emissions in the open economy may fall. The two alternative cases mentioned above assume there is either very little or no technique effect.

In the case where trade allows the expansion of production such that an increase in income is high enough to provide incentive for the regulatory authority to raise the stringency of pollution policy, then firms will undertake greater abatement level and induce a technique effect. In the case where the trade-induced technique and selection effects offset the trade-induced scale effect, trade is good for the environment as it leads to a fall in the level of emissions.

Since there are various alternative possibilities of the combinations of the trade-induced scale, technique and selection effects, the analysis suggests that the question of whether intra-industry trade increases or decreases the total level of emissions is an empirical one.

I will explore the implications of intra-industry trade on environmental quality by testing the predictions of the pollution model in an empirical analysis in a subsequent chapter.

Table A.3 (see Appendix A) summarizes the effects of intra-industry trade on the economic variables of interest: the abatement level, emission intensity, the price level, the scale of production, the number of firms (product varieties), and the total emission in the economy.

2.6 Conclusion

The framework developed in this chapter shows that the pollution intensive production of differentiated goods yields scale, technique and selection effects. The selection effect distinguishes the environmental impact in a model of monopolistic competition and increasing returns, from the composition effect in a model of perfect competition and constant returns.

Comparative statics analysis shows that a change in the stringency of environmental policy generates unambiguous changes in economic variables. In particular, stricter regulation raises firm-level abatement activity, lowers emission intensity, raises product prices, lowers output level, and raises the number of firms in the economy. In addition, it lowers the consumption of product varieties when more stringent policy leads to higher price levels.

The total effect of a change in environmental policy depends on the "policy-induced" scale, technique and selection effects. The analysis shows that while a more stringent regulation increases product price, its effect on emissions level is ambiguous and depends on the sum of the magnitudes of the policy-induced environmental effects of scale, technique and selection. Hence, surprisingly, this result implies that the environmental effect of more stringent environmental policy does not necessarily lead to a decrease in emissions, but that it explicitly imposes a welfare cost on consumption by increasing product price and decreasing consumption levels.

In the open economy, analysis shows that the environmental impact of intra-industry trade can be decomposed into "trade-induced" scale, selection and technique effects. First, free trade is shown to lead to the expansion of the production of dirty goods, a positive trade-induced scale effect that increases emissions. Second, competition from abroad leads to a fall in the number of domestic firms, a negative trade-induced selection effect which reduces emissions level. Third, if income rises with the increase in production, this leads to a negative trade-induced technique effect arising from the income effect of stricter regulation. The negative trade-induced technique effect lowers emissions level. Therefore, the total impact of intra-industry trade on environmental quality is shown to be the sum of the trade-induced scale, technique and selection effects.

CHAPTER THREE

INTRA-INDUSTRY TRADE AND THE ENVIRONMENT

3.1 Introduction

In the last few decades, globalization has given rise to environmental concerns as emerging economies expand dirty sectors to attain high income growths. While international trade augments consumptive welfare, the consequences of pollution intensive production are said to incur costs on overall trade effects. Current and vigorously heated debate on how trade affects environmental quality remains ongoing. To date, literature suggests mixed findings in the determination of whether trade is beneficial or detrimental to the environment.

Presently, most empirical works that explore the environmental effects of international trade are based on the traditional trade theory of comparative advantage and cross-country factor differentials (see Antweiler et al. 2001; Copeland and Taylor 2003; Frankel and Rose 2005). In contrast, "new trade" theory suggests the demand aspect of the economy plays an important role in shaping trade patterns (Krugman 1979; Helpman 1987) where consumer preference for product varieties implies specialization in differentiated goods and market expansions across borders.

Given growing environmental concerns and trade policy issues, an important question to ask is, how does intra-industry trade in final goods affect the environment?

In this paper, I develop a trade-environment framework based on the Krugman (1980) model of monopolistic competition and increasing returns to scale. I explore the environmental impact of trade in differentiated goods under the assumption that the consumer's utility function has the property of constant elasticity substitution (CES). The assumption of CES preference in this paper yields different results than those obtained under the assumption of the more general, non-CES utility function in the framework developed in Chapter Two.

There are two major motivations for using a CES utility function to model the trade-environment relationship. One, trade literature suggests that while the selection effect of intra-industry trade is empirically significant, the scale effect is very small (see Head and Ries 1999, 2001). One possible reason for the negligible scale effect is that goods have constant demand elasticity. Utility functions that exhibit constant elasticity of substitution give rise to constant demand elasticity, thereby providing an explanation for a small scale effect. In the context of trade and pollution, the absence of a trade-induced change in the scale of production implies the absence of a trade-induced environmental scale effect. Therefore, this result presents an alternative outcome of the impact of intra-industry trade which contrasts with the result obtained in Chapter Two. Consequently, an implication of this finding is that divergent empirical results which reflect the different outcomes can be interpreted based on distinct underlying theoretical assumptions.

The CES model is the more dominant framework of intra-industry trade. This is a second and equally important motivation for using a CES utility function in modeling pollution and new trade theory. There are at least two reasons for the more mainstream usage of a CES framework. One, the CES assumption provides greater tractability in analytical modeling, and two, the CES framework lends more easily to the development of extensions to the model. An interesting extension of the CES framework is the incorporation of heterogeneity in firm-level productivity (Melitz 2003). In the context of a pollution model, an application of firm-level heterogeneity is the investigation into the firm's abatement activity with regards to trade and environmental policy concerns. More specifically, a CES trade-environment framework may allow the examination into the question of whether the surviving firm that engages in trade, shown to be the more efficient firm (Melitz 2003) may also be the cleaner firm. The CES model developed in this paper allows extensions to address such heterogeneity issue.

The contributions of this paper are as follows. One, it develops a pollution and intra-industry trade framework assuming homothetic preferences. Two, it offers a comparative statics analysis of the effects of environmental policy changes on economic variables of interest. More specifically, the effects of a more stringent policy are examined under the assumption of both exogenous and endogenous emission tax rates.

This paper shows the following results. First, in a model of pollution and trade where preferences are represented by a CES utility function, there are no trade-induced scale and selection effects. However, if trade increases income level, then the resulting trade-induced technique effect implies a reduction in emission intensity. Therefore, an unambiguous implication of these outcomes is that intra-industry trade does not harm environmental quality. Second, a change in environmental policy leads to changes in the level of abatement undertaken by the firm, but does not yield any change in the firm's scale of production or in the number of firms in the economy. In other words, while there is a policy-induced negative technique effect, policy is neutral with respect to scale and selection effects. An implication of these results is that if the price elasticity of demand is constant, environmental policy imposed on the production does reduce emission intensity, but does not contract the quantity of dirty output or affect the size of the industry engaged in pollution-intensive production.

The remainder of this paper is organized in the following way. Section 3.1 describes the theoretical framework and characterizes its equilibrium. Section 3.2 provides a comparative statics analysis of the effects of changes in environmental policy, section 3.3 presents a bilateral trade model of pollution and trade, section 3.4 presents the discussion and section 3.5 concludes.

3.2 The Model

The Krugman-Dixit-Stiglitz (1980) trade model is extended to incorporate pollution externality: market structure is described by monopolistic competition and production technology is increasing returns and internal to firms. Pollution is jointly generated with goods production where pollutants are locally and uniformly distributed. For simplicity, in this section, I assume emission tax rate is determined exogenously. This assumption is relaxed in section 3.3 in the open economy case.

Notations are as defined in Chapter 2 and I omit redefining them in this chapter.

3.2.1 Demand

Consumers face a constant elasticity of substitution (CES) utility function where the variety of goods and pollution level enter the utility function symmetrically. The utility function is as follows:

(3.1) $$U = \sum_{i=1}^{n} c_i^{\rho} - \sum_{i=1}^{n} \varphi z_i \qquad 0 < \rho < 1,\ \varphi > 0$$

The preference parameter ρ has a value that is between zero and one to reflect the love-of-variety preference (see Dixit-Stiglitz 1977). The parameter φ represents the marginal utility of the damage from pollution.

Consumers have no control over pollution and take pollution as given. Thus, the consumer's maximization problem is as follows:

(3.1') $$\underset{\{c_i\}}{Max} \quad \sum_{i=1}^{n} c_i^{\rho} - \sum_{i=1}^{n} \varphi z_i \qquad \text{subject to} \quad y = w$$

where $$y = \sum_{i=1}^{n} p_i c_i$$

The first order condition for consumer utility maximization is:

(3.2) $$\sum_{i=1}^{n} c_i^{\rho-1} = \frac{\lambda}{\rho} p_i \qquad\qquad i = 1,\ldots,n$$

where λ is the Lagrange multiplier and the marginal utility of income.

3.2.2 Production

Firms maximize profit by taking revenue less factor (labor) costs of production and less the cost of emissions tax payments made to the government. As in Krugman (1980), labor is the sole factor of production in the economy and there is fixed cost. Labor is a linear function of output that takes a particular functional form such that:

(3.3) $$L_i = \alpha + \beta q_i$$

where α is the fixed cost of production.

In the presence of a regulatory authority, emissions tax is high enough so that firms choose to undertake abatement to reduce pollution emission. Firms in the model allocate a fraction, θ, of output as input into the abatement process. Denoting $z_i(\theta_i)$ as net emission after abatement, the relationship between emission and emission per unit output is:

(3.4) $$z_i = e_i q_i$$

Net output is:

(3.5) $$q_i^{net} = q_i(1-\theta_i)$$

Thus, the supply and demand of goods is given by the relationship:

(3.6) $$(1-\theta_i)q_i = Lc_i$$

where L is total labor force, and $(1-\theta_i)$ is the portion of output allocated towards consumption.

The functional form for emission per unit output, e_i, is specified as the following:

(3.7) $$e_i = (1-\theta_i)^{\delta} \qquad \delta > 1$$

Denote π as profit, which is the firm's revenue less labor cost, pollution taxes and abatement cost such that:

(3.8) $$\pi_i = p(1-\theta_i)q_i - w\alpha - w\beta q_i - \tau z_i$$

All firms are identical. Henceforth, subscripts are suppressed.

3.2.3 Autarky Equilibrium

The first order condition with respect to output can be written as the following (see Appendix B for details):

(3.9) $$p\left(1-\frac{1}{\eta}\right) - \tau(1-\theta)^{\delta-1} = \frac{w\beta}{(1-\theta)}$$

where η is the price elasticity of demand for net output.

The first order condition of profit maximization with respect to θ, the fraction of output allocated towards abatement, is given by (see Appendix B for details):

$$\theta = 1 - \left(\frac{w\beta}{\tau(\delta - 1)} \right)^{\frac{1}{\delta}} \tag{3.10}$$

The interpretation of equation (3.10) is identical to the interpretation in the previous Chapter Two and is omitted it here.

Solve for emission intensity by substituting equation (3.10) into equation (3.7) to obtain the equilibrium emission intensity, given by the following:

$$e = \left(\frac{w\beta}{\tau(\delta - 1)} \right) \tag{3.11}$$

Substitution of equation (3.10) into equation (3.9) yields the equilibrium pricing rule, which is (see Appendix B for details):

$$p = \frac{1}{\rho} \left(\frac{\delta}{\delta - 1} \right) \left[(w\beta)^{\delta - 1} \tau(\delta - 1) \right]^{\frac{1}{\delta}} \tag{3.12}$$

The pricing rule is determined by the preference parameter ρ, the emission elasticity parameters, δ, the wage rate w, the labor productivity coefficient β, and the emission tax τ, imposed by the government. Equation (3.12) shows that price is increasing in the marginal cost of production of goods and increasing in the environmental tax rate.

From the zero profit condition, the firm's output level can be determined. Free entry and exit of firms implies that the zero profit condition is given by the following equation:

(3.13) $$p(1-\theta)q - w\alpha - w\beta q - \tau(1-\theta)^{\delta} q = 0$$

Then, by substitution of the equilibrium value of θ, and rearranging, the quantity of output is obtained as follows (see Appendix B for details):

(3.14) $$q = \frac{\alpha\rho(\delta-1)}{\beta\delta(1-\rho)}$$

Equation (3.14) shows that quantity produced depends only on the fixed parameters in the system. Output is an increasing function in fixed cost, the preference parameter and the per unit consumption elasticity of emission per unit; it is decreasing in the inverse of the labor coefficient.

Then, net output, $(1-\theta)q$, is the following (see Appendix B):

(3.15) $$q^{net} = \left(\frac{w\beta}{\tau}\right)^{\frac{1}{\delta}} \left(\frac{\alpha\rho(\delta-1)^{1-1/\delta}}{\beta\delta(1-\rho)}\right)$$

From the demand and supply equation (3.6), the equilibrium level of consumption demand is obtained. Substituting for the equilibrium level of abatement indicated by equation (3.10) gives the following equation:

(3.16) $$c = L^{-1}\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}} \left(\frac{\alpha\rho(\delta-1)}{\beta\delta(1-\rho)}\right)$$

Equation (3.16) shows that consumption level is decreasing in labor, L. An expansion in the population force implies a reduction in consumption as the number of goods available for consumption decreases for each consumer. Equation (3.16) also shows that there is an inverse relationship between consumption level and emission tax rate; consumption is decreasing in the stringency of an emissions tax.

The full-employment condition is:

(3.17) $$L=\sum_{i=1}^{n}\left(\alpha+\beta q_i\right)$$

Use the full employment condition (3.17) to solve for n, the number of product varieties, to obtain the following (see Appendix B):

(3.18) $$n=\frac{L\delta(1-\rho)}{\alpha\left[\delta(1-\rho)+\rho(\delta-1)\right]}$$

Equation (3.18) indicates that the number of firms or product varieties is increasing in labor, *L*. An expansion in the labor force implies an increase in resources or factors of production. This raises the scale of production and the number of product varieties, or equivalently, the number of firms operating in the economy.

The foregoing results in equations (3.10), (3.14) and (3.18) are summarized by the following proposition.

Proposition 3.1: *Consider an economy where market structure is monopolistic competition, production is increasing returns to scale and consumer preference is represented by a constant elasticity of substitution (CES) utility function. Given an emission tax rate, and an elasticity of emission intensity per unit consumption larger than unitary such that* $\delta>1$, *then, (i) the firm's abatement level is a fixed proportion of output, and (ii) the scale of production and the number of firms in the industry are independent of price and abatement levels.*

3.2.4 Scale, Technique and Selection Effects:

Following the analysis is the previous Chapter Two and from equation (3.4), I define the scale, technique and selection effect as follows:

$$\hat{Z} = \hat{n} + \hat{e} + \hat{q} \qquad (3.19)$$

where $\hat{Z}$ is the percent change in total emission, $\hat{n}$ is the percent change in the number of firms (or equivalently, in the number of product varieties), $\hat{e}$ is the percent change in emission per unit output, and $\hat{q}$ is the percent change in the level of output.

Equation (3.19) shows that growth in total emission is the sum of growths in the number of firms, emission intensity and scale of production, which are, respectively, the selection effect, the technique effect, and the scale effect.

3.3 Comparative Statics Effects of Stricter Environmental Policy

Changes in environmental policy can have wide ranging implications on consumer welfare as well as on economic performance. If greater environmental quality, for example, in the form of cleaner air is desirable, then, stricter environmental regulation can be implemented to attain it. However, the imposition of more stringent policy affects the firm's production decisions in the consideration of rising compliance costs. Hence, a trade-off exists between the achievements of environmental objectives and economic objectives. In this section, I analyze the effects of an increase in the stringency of environmental policy. More specifically, the comparative statics effects of an increase in emission tax rate are examined for the following variables: the fraction of output allocated towards abatement, the price level, the levels of output and net output, the consumption level, and the number of firms in the industry.

3.3.1 Abatement

Theoretically, an increase in pollution tax is expected to increase the fraction of output used for abatement. For the cost-minimizing firm, it is efficient to equate marginal abatement cost to the tax rate imposed on emissions (see Baumol and Oates 1988; Hanley, Shogren and White 1997). Thus, if emission tax rates were to increase, then the marginal benefit of reducing emissions level increases.

From equation (3.10), I can show the effect of a change in emission tax rate on the level of abatement level as the following:

$$\frac{\partial \theta}{\partial \tau} = \tau^{-\left(\frac{1+\delta}{\delta}\right)} \left(\frac{w\beta}{(\delta - 1)} \right)^{\frac{1}{\delta}} > 0$$

The result shows that the direction of the relationship between a positive change in emission tax rate and the fraction of output allocated for abatement is positive. Hence, an increase in emission tax rate increases the fraction of output allocated for abatement. Intuitively, in the CES model of intra-industry trade and pollution, the increase in output allocation for abatement implies that the opportunity cost of allocating output towards producing goods for consumption has increased. The increase in the environmental tax rate forces the firm to make a decision on whether to increase the allocation of output for pollution abatement and reduce emission tax payments, or to increase the allocation of output for consumption to increase revenue. The firm will increase the level of abatement as long as the marginal benefit of the incremental abatement level equal the marginal cost of an incremental increase in emission tax rate. When the emission tax rate is raised, equating the marginal benefit of reducing emission equal to the marginal abatement cost means it pays to increase abatement activity; hence, the allocation of output for abatement purposes increases. In other words, more stringent pollution regulation acts as an incentive for the firm to allocate greater amount of resources for abatement purposes.

3.3.2 Emission Intensity

From equation (3.11), the effect of a change in emission tax rate on emission intensity is given by the following:

$$\frac{\partial e}{\partial \tau} = -\tau^{-2}\left(\frac{w\beta}{(\delta-1)}\right) < 0$$

This result shows that an increase in the stringency of environmental policy leads to a lower emission per unit output. An increase in emission tax rate gives firms the incentive to allocate more resources towards reducing pollution. This result is consistent with the theoretical expectation that a more stringent environmental policy leads to the firm's decision to increase its abatement capacity. Further, since the level of abatement is increasing in emission intensity, any factor that increases the level of abatement implies a reduction in per unit emission. Notably, an increase in wage rate or income which leads to an increase in abatement levels will in turn lead to a decrease in emission intensity. This is the policy-induced technique effect.

3.3.3 Price

Equation (3.12) shows that a change in emission tax rate on the product price is:

$$\frac{\partial p}{\partial \tau} = \tau^{\frac{1-\delta}{\delta}} \left(\rho(\delta-1)\right)^{-1}\left[(w\beta)^{\delta-1}(\delta-1)\right]^{\frac{1}{\delta}} > 0$$

That is, a change in the environmental tax rate affects the price level in a positive direction. Hence, an increase in emission tax rate leads to an increase in the price level.

When firms have to make tax payments to internalize the costs of pollution, the profit maximizing firm will equate marginal revenue to marginal cost that is now inclusive of the marginal tax cost (see Baumol and Oates 1988). Hence, the increase in marginal cost is reflected as an increase in the price of goods.

In the current model, the increase in the price level due to an increase in emission tax rate can be explained in the following way. An emission tax rate increase implies that the firm increases abatement activity to lower emission intensity and to reduce tax payments. Consequently, there is a trade-off between using resources for the production of consumption goods versus using the same resources for undertaking abatement. An increase in pollution which entails stricter environmental regulation constitutes a resource cost – more abatement is required to deal with the emission increase which in turn diverts resource use from the purpose of consumption goods' production. The resulting scarcity of resources in the goods production is reflected in an increase in the price level. The greater the change in emission intensity due to greater abatement, or in other words, the greater the change in the fraction of output allocated towards abatement, the higher is the increase in the price level.

3.3.4 Consumption

Consumption level decreases with the increase in emission tax rate. Equation (3.16) shows the effect of a change in emission tax rate on consumption level as follows:

$$\frac{\partial c}{\partial \tau} = -\tau^{-\frac{(1+\delta)}{\delta}} \left(\frac{w\beta}{(\delta - 1)} \right)^{\frac{1}{\delta}} L^{-1} q < 0 .$$

The result shows that a stricter environmental policy induces a reduction in the consumption of goods. Intuitively, there are two reasons for the resulting decrease in consumption. One, a higher emission tax rate implies it pays the firm to allocate a greater amount of resources (output) towards the abatement of emissions. Since total output is used for both abatement and consumption, then the trade-off between allocating a fraction of output towards abatement and the remaining fraction towards consumption implies that the more stringent the environmental policy, the less the amount of output allocated for consumption purposes. Thus, this means a higher emission tax rate leads to lower consumption levels. A second reason for decrease in consumption is that higher tax payment implies higher marginal cost of production, which leads to an increase in product price. The increase in the price level leads to a decrease in the quantity of goods demanded.

3.3.5 Net Output

Equation (3.14) indicates that equilibrium net output is an inverse function of emission tax rate such that:

$$\frac{\partial q^{net}}{\partial \tau} = -\tau^{-\left(\frac{1+\delta}{\delta}\right)} \frac{(w\beta)^{\frac{1}{\delta}}}{\delta} \left(\frac{\alpha\rho(\delta-1)^{1-1/\delta}}{\beta\delta(1-\rho)} \right) < 0 .$$

The result implies that an increase in emission tax rate leads to a reduction in net output produced for consumption purposes, while a decrease in emissions tax rate leads to a rise in the level of net output. There is a trade-off between using output as resource for abatement versus using it for increasing revenue from sales of consumption goods. Therefore, the higher the emissions tax rate, the more resource or output is required for abatement purposes, consequently leaving less net output produced for the purpose of goods consumption. In contrast, if tax rate were lowered, a greater fraction of output would be allocated for the purpose of filling market demand for consumption, hence net output increases with a decrease in emission tax rate.

3.3.6 Output

Equation (3.16) shows that total output produced in the economy is not a function of the emissions tax rates.

$$\text{Therefore, } \frac{\partial q}{\partial \tau} = 0.$$

In this model, a change in the stringency of environmental regulation has no effect on the total level of output produced. This outcome is consistent with the assumptions of a CES utility function and a constant elasticity of demand which leads to the result that the scale of production that is independent of price and abatement levels. Hence, notably, the zero effect of emission tax rate on the scale of production means environmental policy is neutral with respect to total output. This is the policy-neutral scale effect.

3.3.7 Number of Firms

The number of firms operating in the economy is independent of emission tax rate as shown by equation (3.16). A change in emission tax rate on the number of firms is given by the following:

$$\frac{\partial n}{\partial \tau} = 0.$$

In the model with CES utility function, the equilibrium number of firms is not affected not a function of emission tax rate. Thus, a change in the stringency of environmental policy has no effect on the number of firms, or equivalently, on the number of product varieties. Therefore, the pollution model of monopolistic competition generates a policy-neutral selection effect.

The results of the foregoing comparative statics analysis of the effects of environmental policy on the firm's abatement level, product price, emission intensity, the level of consumption, net output, total output and the number of firms are summarized by the following proposition.

Proposition 3.2: *Consider an economy that engages in the production of differentiated, dirty goods. Preferences are homothetic with constant elasticity of substitution. Then, an increase in the stringency of exogenous environmental policy leads to (i) an increase in the firm's abatement level; (ii) an increase in the price of product varieties; (ii) a decrease in emission intensity; (iv) a decrease in the level of consumption; (v) a decrease in net output, (vi) no effect on total output; and, (vii) no effect on the number of firms in the economy. Notably, a stricter environmental policy induces a negative technique effect but generate policy-neutral scale and selection effects.*

3.4 Bilateral Trade

In this section, I consider a two-country world where both economies are identical in production technology and preferences. Constant elasticity of substitution between goods is assumed. The model shows the following results. One, the number of domestic firms, the level of consumption, the level of output, the level of abatement and the price level are shown to be functions of predetermined factors. Two, welfare gain from trade comes from the increase in the number of product varieties available to consumers through imports. Three, there are no trade-induced scale, technique or selection effects.

The world consists of two countries, Home (H) and Foreign (F), engaged in the trade of dirty goods. Monopolistic competition market structure prevails, characterized by technology that is increasing returns to scale and is internal to firms (Krugman 1980). Consumers have Dixit-Stiglitz type preferences, where a CES utility function is maximized subject to a budget constraint. Pollution that is jointly generated with dirty goods production is locally and uniformly released into the environment. A regulatory authority levies an emissions tax to internalize the negative externality of pollution. Firms maximize profits taking into account the emission tax rate.

3.4.1 Consumption

Let $i = 1,...,n$ index the number of varieties produced domestically, and $I = 1,...,n^*$ index the number of varieties produced abroad. Small letters denote Home variables, while letters with asterisks denote Foreign variables, with the exception of the index of the number of product varieties, where small letter denotes Home and capital letter denotes Foreign. Demand or consumption at Home (Foreign) is denoted by $c\left(c^*\right)$, abatement level by $\theta\left(\theta^*\right)$output level by $q\left(q^*\right)$, price by $p\left(p^*\right)$, imports by $m\left(m^*\right)$, total income by $y\left(y^*\right)$, wage by $w\left(w^*\right)$, and emissions tax by $\tau\left(\tau^*\right)$.

The representative consumer's utility function for the Home country (and similarly for the Foreign country) is a function of the consumption of product varieties produced at home (c_i) and imported varieties (m_I) produced abroad, and a disutility of pollution externality associated with production of domestic products (z_i). The preference parameter, ρ , and the elasticity of substitution between any two goods, $\sigma = (1-\rho)^{-1} > 1$, are assumed identical for both countries.

The utility functions for Home and Foreign are as follows:

(3.20) $$U^H = \sum_{i=1}^{n} c_i^\rho + \sum_{I=1}^{n^*} m_I^\rho - \sum_{i=1}^{n} \varphi z_i \qquad 0 < \rho < 1$$

(3.21) $$U^F = \sum_{I=1}^{n^*} c^{*\rho}_I + \sum_{i=1}^{n} m^{*\rho}_i - \sum_{I=1}^{n^*} \varphi z^*_I$$

where φ is the disutility of emission.

The budget constraint is total income composed of wage earned, w such that $w = y$ (and similarly for Foreign). Then, the budget constraint implies:

(3.22) $$y = \sum_{i=1}^{n} p_i c_i + \sum_{I=1}^{n^*} p^*_I m^*_I$$

(3.23) $$y^* = \sum_{I=1}^{n^*} p^*_I c^*_I + \sum_{i=1}^{n} p_i m_i$$

Henceforth, I will write results for the Home country, keeping in mind that the Foreign country will have similar results.

Following Dixit and Stiglitz (1977), and as in Gurtzgen and Rauscher (2000), the levels of consumption are given by the following equations:

$$c_i = \frac{p_i^{1/(\rho-1)}}{np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}} \cdot y \tag{3.24}$$

$$m_I = \frac{p^*{}_I^{1/(\rho-1)}}{np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}} \cdot y \tag{3.25}$$

3.4.2 Production

Since Home and Foreign are identical in terms of endowments and technology, supply side conditions for the Foreign country mirror domestic supply (as in Home autarky conditions). Home country equilibrium conditions are characterized in the previous Chapter Two, while Foreign country equilibrium conditions are given below:

$$\theta^* = 1 - \left(\frac{w^* \beta^*}{\tau^* \left(\delta^* - 1 \right)} \right)^{\frac{1}{\delta^*}} \tag{3.26}$$

$$p^* = \frac{1}{\rho^*} \left(\frac{\delta^*}{\delta^* - 1} \right) \left[\left(w^* \beta^* \right)^{\delta^* - 1} \tau^* \left(\delta^* - 1 \right) \right]^{\frac{1}{\delta^*}} \tag{3.27}$$

$$q^* = \frac{\alpha^* \rho^* \left(\delta^* - 1 \right)}{\beta^* \delta^* \left(1 - \rho^* \right)} \tag{3.28}$$

$$q^{*net} = \left(\frac{w^* \beta^*}{\tau^*} \right)^{\frac{1}{\delta^*}} \left(\frac{\alpha^* \rho^* \left(\delta^* - 1 \right)^{1 - 1/\delta^*}}{\beta^* \delta^* \left(1 - \rho^* \right)} \right) \tag{3.29}$$

$$n^* = \frac{L^* \delta^* \left(1 - \rho^* \right)}{\alpha^* \left[\delta^* \left(1 - \rho^* \right) + \rho^* \left(\delta^* - 1 \right) \right]} \tag{3.30}$$

Proposition 3.3: *Consider two identical economies engaged in bilateral intra-industry trade. Then, in the open economy, when the price elasticity of demand is constant, firm-level abatement, scale of production and the number of firms are unaffected by free trade. Consequently, there are no trade-induced environmental scale, technique or selection effects. However, free trade implies as if there is an increase in domestic labor force, which increases the number of product varieties available for consumption.*

PROOF:

Equation (3.18) implies $\partial n/\partial L > 0$ so that an increase in the labor force leads to an increase in the number of product varieties. In a two-economy world, the integrated world economy implies as if there is a doubling in the labor force (Krugman 1980), such that the total number of varieties available for consumption is $N = n + n^{*}$. This leads to a trade-induced selection effect in terms of consumption. Further, equation (3.16) implies that consumption of domestic product varieties decreases with an increase in labor force, that is, $\frac{\partial c}{\partial L} < 0$ and the doubling of labor forces implies a reduction in consumption of domestic product by half. However, without an actual change in the labor force so that $dL = 0$, there is no change in the scale of production or in the number of firms in the economy. Therefore, there are no trade-induced environmental scale, technique or selection effects.

3.4.3 Pollution Supply and Emission Tax

In this section, I solve for pollution supply as determined by the price of pollution emission (Antweiler et al. 2001). I assume that the regulatory authority levies an emissions tax to internalize pollution externality. Following Gurtzgen and Rauscher (2000), the consumer's utility function is optimized with respect to emission tax rate. Substituting for equilibrium values, welfare is maximized given the production constraint and the full employment condition.

I note that policy instruments such as an emission tax rate which internalizes pollution damage, may not correct for the allocative inefficiency associated with market power. An emission tax rate may exacerbate the social cost of a suboptimal level of production due to monopoly pricing (Carraro 1998). On the other hand, in models of contestable market with preferences for differentiated goods, economies of scale in production may imply more efficient use of inputs. Therefore, greater efficiency in the employment of factors of production and a suboptimal level of output may contribute to reducing pollution level. In addition, consumers may associate these aspects as "green" qualities of product differentiation. Hence, both the increase in utility from the consumption of environmental-friendly goods and the decrease in pollution due to the technology of economies of scale may offset some of the welfare loss due to suboptimal levels of production and consumption.

To solve for the consumer-welfare maximizing emission tax rate[8], the demand equations in (3.22) and (3.23) are substituted into equation (3.20) to obtain the indirect utility function:

$$V^H = \frac{y^\rho\left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)}{\left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)^\rho} - n\varphi z \tag{3.31}$$

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8 As noted, the consumer-welfare maximizing emission tax rate in a model of monopolistic competition is a second best tax rate since it does not correct for the welfare loss due to market power and thus does not correct for allocative inefficiency.

where $y = w$. Then, p, $p*$, n, and $n*$ are as given in equations (3.12), (3.27), (3.18) and (3.30) respectively.

Subsequently, identical preference and technology across countries implies (3.31) can be written as:

$$V^H = \frac{(\tau n z)^\rho \left(n p^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)}{\left(n p^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)^\rho} - n\varphi\tau^{-1}\left(\frac{w\beta}{(\delta-1)}\right)q \tag{3.32}$$

Solve for environmental policy by maximizing equation (3.32) with respect to emission tax rate, τ. The first order condition is:

$$\frac{\partial V^H}{\partial \tau} = \frac{\rho\tau^{\rho-1}(nz)^\rho \left(n p^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)}{\left(n p^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)^\rho} + n\varphi\tau^{-2}\left(\frac{w\beta}{(\delta-1)}\right)q = 0$$

Solving for emission tax rate yields the following equation:

$$\tau = -\left[\left(\frac{1}{\psi}\right)\varphi\rho^{-1}\left(\frac{w\beta}{(\delta-1)}\right)q\right]^{\frac{1}{1+\rho}} \tag{3.33}$$

where

$$\psi = \frac{\left(n p^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)}{\left(n p^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)^\rho}$$

Equation (3.33) is the Samuelson rule where the term on the right hand side of the equation indicates the marginal damage of pollution for each consumer. The equation shows the emission tax rate is a function of the fixed level of output (see equations (3.13)), the marginal disutility for pollution, the numbers of product varieties produced at home and abroad (see equations (3.18) and (3.30) respectively), the world price level, and the wage rate.

Notably, equation (3.33) implies that an increase in the wage rate, or income, leads to an increase in emission tax rate so that:

$$(3.34) \qquad \frac{\partial \tau}{\partial w} = (1+\rho) w^{-(2+\rho)} \left[\left(\frac{1}{\psi} \right) \varphi \rho^{-1} \left(\frac{\beta}{(\delta - 1)} \right) q \right]^{\frac{1}{1+\rho}} > 0$$

Thus, equation (3.34) shows that an increase income or the wage rate leads to an increase in the stringency of environmental regulation. This result provides a basis for the technique effect: higher income levels, which leads to a more stringent environmental policy, induces greater abatement level undertaken by the firm and hence lower emission intensity (see section 3.2). In other words, given that environmental quality is a normal good, an increase in income implies a decrease in emission intensity through an increase in the stringency of environmental policy.

3.5 Discussion

In a pollution model of monopolistic competition and increasing returns to scale with CES utility function, constant price elasticity of demand leads to the result that for a given exogenous emission tax rate, abatement is a fixed proportion of output and is decreasing in emissions tax rate. In addition, the firm's output level and the number of firms in the economy are shown to be independent of the price and abatement levels. Consequently, autarky equilibrium implies a policy-induced technique effect, but does not generate scale and selection effects. Environmental policy is neutral with respect to the scale of production and the size of the industry. Hence, in a model where preferences exhibit CES, environmental policy addresses the efficiency in the abatement aspect of pollution emission solely. These results are distinct from the results obtained under the assumption of non-CES and non-homothetic preferences shown in Chapter Two, where a more stringent environmental policy generates policy-induced scale, technique and selection effects.

An important implication of the outcomes of the foregoing analysis is that environmental policy implementation needs to take into account not only the structure of the market, but also the elasticity of demand for goods. Policy effects in markets where constant returns to scale and perfect competition prevail yield policy-induced scale, technique and composition effects (Antweiler et al. 2001). On the other hand, in markets where increasing returns and monopolistic competition prevail, policy effects yield scale, technique and selection effects (Chapter Two). However, in the latter where the additional restriction on demand elasticity is assumed to be constant, policy effect is limited to the technique effect, as shown in the current analysis.

In the open economy analysis, the CES model implies the complete absence of trade-induced environmental effects. Free trade does not yield any change in the production side of the economy, leaving the environment unaffected by trade activities. Therefore, when preferences for goods have constant elasticity of substitution, the result is unambiguous: intra-industry trade does not harm the environment. This result contrasts the findings in Chapter Two where the analysis shows that a non-CES utility function generates trade-induced positive scale, negative technique and positive selection effects.

In the non-CES, more general case, the impact of intra-industry trade is shown to be the sum of the trade-induced scale, technique and selection effects.

Finally, the foregoing analysis suggests that the question of whether international trade in dirty, differentiated goods raises or lowers emissions level is an empirical one. The realization of data and responses to the scale, technique and selection effects of intra-industry trade will depend on economic factors that determine how pollution-intensive production influences environmental quality. I explore the answer to this question in the next chapter by undertaking an empirical analysis to attempt to find evidence in the data and estimate the impact of intra-industry trade on emission levels.

3.6 Conclusion

The model developed in this paper offers a number of insights into the trade-environment relationship for countries that trade in differentiated goods. First, in a pollution model of trade where preference is represented by a CES utility function, there are no trade-induced scale, technique or selection effects. This result suggests that free trade does not necessarily contribute to raising emissions level when countries engage in pollution-intensive production. Hence, if demand elasticity is constant, the CES model of pollution implies that intra-industry trade is good for the environment as it increases the number of product varieties available for consumption without imposing negative environmental effects. Dirty production is confined within domestic borders. Second, under the assumptions of increasing returns and CES utility functions, an increase in the stringency of environmental policy in a monopolistically competitive industry does not lead to any change in the scale of production or in the number of firms. There is, however, a reduction in emission intensity when firms face stricter regulation. Therefore, greater stringency leads to a policy-induced technique effect but is neutral with respect to scale and selection effects. The important implication of this result is that the implementation of changes in environmental policy needs to be market specific – the effects of policy may differ across industries in accordance with differences in production technology, market structure and consumer preference.

CHAPTER FOUR

HOW DOES INTRA-INDUSTRY TRADE AFFECT THE ENVIRONMENT?

4.1 Introduction

In this paper, I investigate the empirical relationship between international trade and environmental quality for countries that engage in both intra- and inter-industry trade. The analysis uses pollution data from the Organization for Economic Co-operation and Development (OECD) for the years 1995-2004. Three types of pollutants are considered, namely, sulfur oxides (SOx), nitrogen oxides (NOx) and volatile organic compounds (VOC). Estimating equations are based on the predictions of two main theoretical frameworks. The first framework is the pollution model of intra-industry trade developed in the previous chapters (Two and Three), which generates the environmental effects known as the "scale", "technique" and "selection" effects. The second framework is the pollution model of inter-industry trade developed by Antweiler, Copeland and Taylor (2001) which generates the "scale", "technique" and "composition" effects.

This is the first study to integrate the trade-induced environmental impacts of both intra- and inter-industry trade. In particular, it examines the selection effect as an important factor to be accounted for in the estimation of the environmental impact of international trade.

Investigations into the trade-environment linkage have mainly sought to address the welfare effect of international trade. Studies attempt to answer the heatedly debated question of whether dirty trade contributes to increasing emission levels and thus negate the benefits of cross-border exchanges of goods. While it is recognized that free trade increases consumptive welfare, concerns are raised about the environmental cost of dirty production and whether globalization can lead to net welfare gains. A number of empirical studies indicate that trade liberalization is good for the environment (see Antweiler et al. 2001). Notably, the majority of empirical studies investigating the trade-environment linkage are based on the traditional theory of trade.

Table 1.1 shows data on manufacturing intra-industry trade as a percentage of total manufacturing trade. The statistics indicate that the volume of trade in differentiated goods has risen for many developing and newly-emerging markets. However, although intra-industry trade explains a significant volume of trade patterns, currently there is no empirical study that investigates the impact of "new" trade on domestic local pollutants. Further, theory suggests that the environmental impact of intra-industry trade is distinct from the environmental impact of inter-industry trade (see Chapters Two and Three). Therefore, if countries engage in both inter- and intra-industry trade[9], an empirical assessment of how international trade affects environmental quality should account for the impact of both types of trade. There has not been a study that assesses the full impact of trade under the assumption that countries engage in both intra- and inter-industry trade.

This paper analyzes the effects of scale, technique, selection and composition on environmental quality. Additionally, it examines the effect of openness to trade on

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[9] The World Bank (2009) calculates and makes available data on Intra-industry Trade (IIT) Index and the Revealed Comparative Advantage (RCA) Index. The IIT index can be computed for any country and is generally computed for the manufactured goods traded Standard Industrial Trade Classification (SITC) three-digit level.

Table 1.1: Manufacturing intra-industry trade as a percentage of total manufacturing trade

	1988-91	1992-95	1996-2000	Change
High and increasing intra-industry trade	n.a.	66.3	77.4	11.1
Czech Republic	n.a.	69.8	76.0	62.2
Slovak Republic	62.5	74.4	73.4	10.9
Mexico	54.9	64.3	72.1	17.2
Hungary	67.1	72.0	72.0	5.0
Germany	63.5	65.3	68.5	5.0
United States	56.4	61.7	62.6	6.2
Poland	52.4	56.3	61.3	8.9
Portugal				
High and stable intra-industry trade				
France	75.9	77.6	77.5	1.6
Canada	73.5	74.7	76.2	2.7
Austria	71.8	74.3	74.2	2.4
United Kingdom	70.1	73.1	73.7	3.6
Switzerland	69.8	71.8	72.0	2.2
Belgium/Luxembourg	77.6	77.7	71.4	-6.2
Spain	68.2	72.1	71.2	3.0
Netherland	69.2	70.4	68.9	-0.3
Sweden	64.2	64.6	66.6	2.4
Denmark	61.6	63.4	64.8	3.2
Italy	61.6	64.0	64.7	3.1
Ireland	58.6	57.2	54.6	-4.0
Finland	53.8	53.2	53.9	0.1
Low and increasing intra-industry trade				
Korea	41.4	50.6	57.5	16.1
Japan	37.6	40.8	47.6	10.0
Low and stable intra-industry trade				
New Zealand	37.2	38.4	40.6	3.4
Turkey	36.7	36.2	40.0	3.3
Norway	40.0	37.5	37.1	-2.9
Greece	42.8	39.5	36.9	-5.9
Australia	28.6	29.8	29.8	1.2
Iceland	19.0	19.1	20.1	1.1

Source: OECD International Trade Statistics, OECD Economic Outlook 71, OECD 2002

emissions level. The full impact of international trade on the environment is estimated as the sum of the magnitudes of four environmental effects[10], that is, as the aggregation of

[10] The empirical study by Antweiler et al. (2001) investigated three environmental effects, namely the scale, technique and composition effects using the framework based on the traditional theory of trade.

the responses to the scale, technique, selection and composition effects. In accounting for the selection effect, this paper controls for an important variable that describes the data generating process of a trade-environment relationship for countries engaged in both intra- and inter-industry trade. In other words, the inclusion of the selection effect variable in the model addresses the omitted variable problem in estimation.

In addition, the analysis in this paper recognizes two major concerns in translating theory into the application of data. One concern is whether to assume, on one hand, that data generates the realization that a country engages solely in either intra- or inter-industry trade; or on the other hand, that data generates the realization that countries engage in both intra- and inter-industry trade. The difference in assuming one assumption instead of the other is that each may yield different interpretations of the results of data analysis. More specifically, if countries are assumed to engage solely in intra-industry trade, then the environmental consequences of international trade may be described by three environmental effects, namely the scale, technique and selection effects. Conversely, if countries are assumed to engage solely in inter-industry trade, then the impact of international trade may be described by the scale, technique and composition effects. On the other hand, if countries are assumed to engage in both intra- and inter-industry trade and that the trade flows for any one country are comprised of both differentiated and homogeneous goods, then the impact of trade on environmental quality requires that the consequences of international trade be described by the four environmental effects, namely, the scale, technique, selection and composition effects.

The second concern involves the definition and measurement of the scale and technique effects in the data. Data used to measure the scale of production is normally represented by the Gross Domestic Product (GDP). Since GDP does not distinguish between the change in the scale of production due to a change in the supply of differentiated goods from that which is due to a change in the supply of homogeneous goods, it is reasonable to assume that the environmental scale effect represented by changes in GDP is the combined effect of the changes from both the production of differentiated and of homogenous goods. In a similar reasoning, the technique effect as measured by the change in income or Gross National Income[11] should constitute the combined effects of the change in emission intensity that is due to both the abatement of differentiated goods and the abatement of homogenous goods. In this paper, it is recognized that the scale and technique effects as represented by GDP and Income, respectively, measure the effects of both inter- and intra-industry trade.

The empirical approach in this paper addresses the foregoing issues in the following ways. First, I specify an empirical model which takes into account the distinct effects of both intra- and inter-industry trade. Therefore, the analysis assumes that countries in the study sample engage in the production of both differentiated goods (intra-industry trade) and homogeneous goods (inter-industry trade). Consequently, the analysis controls for both the composition effect arising from comparative advantage due to cross country factor differentials and the selection effect arising from the specialization due to economies of scale.

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[11] The technique effect is the change in emission intensity as firms undertake changes in the abatement of pollution to meet environmental regulation standards. Since environmental quality is a normal good, the higher the income level the more stringent environmental regulation will be. Thus the change in emission intensity can be represented by the change in income level (see ACT, 2001) where an increase in income level is associated with a decrease in emission intensity.

Second, since data for the scale and technique effects measure both inter- and intra-industry production effects, I interpret the estimates for scale and technique effects as estimates that represent the integrated environmental effects of an economy that engages in both inter- and intra-industry trade. In other words, the analysis recognizes that there is no distinction or separation based on types of trade in the measurements of the scale and technique effects.

The contributions of this paper are as follows. One, it builds an empirical model of the trade-and-environment relationship which integrates the effects of both intra- and inter-industry trade. Two, it tests the theoretical predictions of the environmental effects of trade measured by the scale, technique, selection and composition variables. In particular, it tests the response to the selection effect on emissions level. Three, it investigates the impact of trade on three types of pollutants, namely, sulfur oxides (SOx), nitrogen oxides (NOx) and volatile organic compounds (VOC). Four, the study contributes a new and original dataset that spans a recent time period, from the year 1995 to year 2004. Five, it provides evidence to attempt to answer the central question, is trade beneficial to the environment?

The findings of this paper are the following. First, evidence suggests that in addition to the scale, technique and composition effects, the selection effect is an important factor in describing the empirical relationship between trade and pollution. Estimation results suggest that the exclusion of the selection effect variable poses a specification error in the form of omitted variable bias in estimation. Second, the signs or directions of the effects of the four environmental variables conform to theoretical expectations. Estimates show that emission levels are increasing in the selection, scale effect, composition and technique effects. The latter implies that emission is decreasing in the stringency of environmental regulation. Third, data on OECD countries suggests that the scale and technique effects can be described by homothetic production or consumption functions, consistent with the underlying theoretical assumptions of intra-industry trade frameworks. Fourth, there is evidence to suggest that greater openness to trade leads to a decrease in emission levels, that is, freer trade contributes to improving environmental quality.

This paper is organized as follows. Section 4.2 discusses the conceptual framework and research hypotheses. Section 4.3 presents the economic model of monopolistic competition, trade and environment which provides the basis for the predictions of the effects of intra-industry trade on emissions level. Section 4.4 derives the reduced form equations for an econometric model of trade-and-environment. Section 4.5 discusses the empirical strategy, section 4.6 presents the main results section while section 4.7 presents the results of alternative model specifications. Section 4.8 is discussion and section 4.9 concludes.

4.2 Conceptual Framework and Research Hypotheses

Theory suggests that the benefits and costs of both the production and the consumption of pollution-intensive goods determine the demand and supply of pollution levels. Economic factors that influence the demand and supply of dirty goods include the price of goods, the factor intensity used in production, the output level of production and the price of environmental regulation (see Antweiler et al. 2001). In Chapter Three of this dissertation, I show that the demand and supply of pollution depends on the number of firms in the industry in addition to other economic factors such as the environmental tax rate and the level of output. Therefore, observable variables in an empirical model that relates pollution levels to economic factors may include the aforementioned variables, including goods or product prices, the factor intensity of production, the level of output and the number of firms.

In the following discussion, I define concepts of environmental variables and their relationships to pollution levels. Empirical hypotheses to be tested are based on the theoretical predictions derived in previous frameworks (see Chapters Two and Three; Antweiler et al. 2001).

4.2.1 Conceptual Framework

Theory suggests intra- and inter-industry trade generates four environmental effects, namely the scale, technique, selection and composition effects. In the following, I relate each environmental variable to pollution.

The first environmental effect considered is the scale effect. In pollution-intensive industries, the expansion of the scale of production implies a simultaneous increase in the joint production of pollution. For example, economic growth that leads to growth in the transportation industry implies growths or increases in emission levels of nitrogen oxides, carbon monoxide, carbon dioxide and non-methane hydrocarbon. The scale effect measures the environmental impact of the growth in the scale of production given there are no changes in emission intensity, in the number of firms in the industry, and in the factor intensity of production. Therefore, if the engagement of trade expands economic production by five percent, then the scale effect implies there will be a five percent increase in the level of pollution, holding all other factors constant.

The seminal paper by Grossman and Krueger (1991, p. 3) defines the scale effect as the increase in pollution level when trade and investment liberalization expands economic activity "if the nature of that activity remains unchanged". Antweiler et al. (2001) defines the scale effect as the increase in the level of pollution due to an increase in the growth of production, holding the technique and composition effects constant. Antweiler et al. (2001) measure the scale effect as the value of GDP at base-period world prices; their study provides evidence to suggest a positive relationship between growth in the scale of production and growth in emissions level.

In this paper, I distinguish the scale effect of intra-industry trade from the scale effect of inter-industry trade. The former arises from the growth or expansion in the production of differentiated goods while the latter arises from the expansion of the production of homogenous, inter-industry goods. Notably, this distinction cannot be discerned in the data when the scale effect is measured as the value of gross domestic product (GDP) at world prices since GDP reflects the value of total national production of all goods. Therefore, when the scale effect is represented by GDP, the analysis in this paper recognizes that the scale effect constitutes the effects from both the production of differentiated and the production of homogeneous goods. This recognition emphasizes the explicit distinction that should be made between the scale effect arising from intra-industry trade and the scale effect arising from inter-industry trade.

The second environmental effect included as an explanatory variable in the current analysis is the technique effect. In this paper, the technique effect is defined as the effect of a change in emission intensity on environmental quality, holding the scale, selection and composition effects constant. There are two major ways to generate the technique effect. One, the technique effect is related to the level of abatement that a firm undertakes. Holding every other factor equal, greater abatement levels will reduce emission per unit output, thereby allowing for a decrease in total emissions level in the economy. Two, the technique effect may also be sourced from the cross-country diffusion of efficient abatement techniques. Multinational firms that relocate to countries with lax environmental regulations may introduce more sophisticated abatement technology into host countries.

The technique effect arising from international trade occurs not only for inter-industry trade goods but also for intra-industry goods. Assuming environmental quality is a normal good, when trade leads to higher income levels, it in turn leads to more stringent environmental regulation. Consequently, firms increase abatement activities to comply with stricter environmental standards. The response to policy requirements applies in any, or both industries engaged in the production of differentiated or homogeneous goods.

Grossman and Krueger (1991, p. 4) define the technique effect as a change in the per unit output of pollution subsequent to trade liberalization and foreign investment. In their study, Grossman and Krueger (1991, 1993) find evidence to suggest that income per capita and pollution levels can be described by the phenomenon now known as the Environmental Kuznets Curve (EKC). The environmental Kuznets curve is the hypothesis which states that pollution levels rise with per capita income, reach a peak, and then fall with the continued increase in per capita income. This finding seems to suggest that as countries become more developed and income level rises, environmental quality as a normal good improves with higher income levels, which subsequently leads to a decrease in per unit output of pollution. Antweiler et al. (2001) define the technique effect as growth in emission intensity, holding everything else constant. The authors use a one-period-lagged, three-year moving average of per capita gross national product (GNP) to represent the technique effect. The authors find evidence to suggest that there is a negative relationship between per capita income levels and total emissions.

The third environmental effect and explanatory variable in the current analysis is the selection effect. The framework I developed in the previous chapters shows that the selection effect distinguishes the environmental impact of trade driven by cross-country demand factors from the environmental impact of trade driven by cross-country factor abundance differentials, namely the composition effect. In the model of monopolistic competition, I define the selection effect as the change in the level of emissions due to a change in the number of firms engaged in the production of differentiated products, holding the scale and technique effects constant. Everything else equal, including the scale effect, fewer numbers of firms leads to lower levels of emission.

The selection effect arises from the assumptions that market structure is imperfectly competitive, that production is increasing returns, and that equilibrium is conditional on the achievement of long run zero economic profits. In this setting, free trade implies that foreign competition leads to a decrease in the number of domestic firms as consumers choose to consume both domestic and foreign products under a constrained budget. Therefore, a trade-induced selection effect implies that holding all other factors constant, the fall in the number of firms leads to a fall in aggregate emissions level. That is, there is a positive relationship between environmental quality and the number of firms, ceteris paribus.

I note that the environmental effect of selection varies in accordance with assumptions imposed on consumer preferences. In a model which assumes non-CES, non-homothetic utility function, international trade in differentiated goods yields a change in the number of firms (or equivalently, in the number of product varieties) which gives rise to a change in environmental quality. In contrast, in a model which assumes a CES utility function, trade in differentiated goods does not affect the number of firms in the economy. This means that openness to trade is neutral with respect to the selection effect.

Literature suggests there is evidence to support a selection effect (Head and Rice 1999). Free trade leads to a reduction in the number of domestic firms as competition from abroad implies some firms earn negative profit and leave the industry. In the context of the environment, a smaller number of firms lead to lower pollution levels, holding other factors constant. In this case, consumers are better off as trade allows an increase in the number of product varieties available for consumption while the smaller number of surviving firms implies less pollution is generated, everything else equal. The empirical analysis in this paper attempts to provide evidence on whether the selection effect leads to a neutral or a positive selection effect.

The fourth environmental variable included as an explanatory variable in the current analysis is the composition effect. Grossman and Krueger (1991, p. 4) define the composition effect as the change in the composition of sectors due to trade liberalization derived from two sources: one, from the competitive advantage in environmental regulation in the pollution-intensive sector, and two, from comparative advantage in cross-country differentials in factor abundance and technology in pollution-intensive activities. Antweiler et al. (2001) define the composition effect as the change in emissions level due to a change in the factor intensity employed in the production in dirty goods, holding the scale and technique effect constant.

The composition effect contrasts with the selection effect of intra-industry trade as the former is generated in the production of inter-industry, homogenous goods, while the latter is generated in the production of intra-industry, differentiated goods. In the Heckscher-Ohlin trade framework where markets are perfectly competitive, changes in goods' prices yield changes in relative factor intensities employed in the production of specialized goods which provides comparative advantage. Therefore, if the economy holds a comparative advantage in the production of dirty goods, this leads to an increase in factor intensity when the dirty sector expands. Consequently, a trade-induced composition effect implies that an increase in the factor intensity employed in the dirty sector leads to an increase in the level of emissions.

A final variable of interest is the trade intensity variable, which measures openness to trade and the degree of trade liberation. Openness to trade is defined by the absence of restrictions that would hinder free trade between trading nations, while trade liberalization is defined as the removal or reduction of trade barriers that restrict the free flow of goods and services across countries. Barriers to free trade include tariff and non-tariff barriers.

In translating the assumption of free trade in the theoretical model into data, most empirical models control for cross-country differences in trade restrictions by including the trade intensity variable as a measure of trade openness. Similarly, in quantifying the effects of trade liberalization, the trade intensity variable is used to measure the degree to which countries may engage in the reduction of trade barriers (see Antweiler et al. 2001). In the current analysis, the trade intensity variable is used to measure two kinds of effects. One, it is used in interaction forms to measure the responses to trade-induced scale, technique, selection and composition effects. Two, it measures the effect of free trade and trade liberalization on environmental quality. On the former, the aggregate effect of trade on environmental quality is the sum of the effects of each of the four environmental effects. On the latter, the effect of trade openness on environmental quality is the estimated marginal effect of a change in emissions level with respect to a unit change in the trade intensity variable.

4.2.2 Research Hypotheses

The main objective of this paper is to examine the impact of international trade on the level of pollution. More specifically, this paper investigates the empirical relationship between emission levels and the scale, technique, composition and selection effects for countries known to engage in the trade of both differentiated and homogeneous goods. Additionally, it examines the effect of trade intensity on environmental quality.

The exchange of differentiated goods, or intra-industry trade, is driven by factors that explain market power and scale economies. There has not been an empirical study that specifically addresses factors that influence the environmental effects of intra-industry trade, namely the selection, scale and technique effects. Notably, the selection effect is specific to intra-industry trade and has not been estimated in any study.

Additionally, the scale and technique effects arising from the production of differentiated goods have not been explicitly shown to generate similar effects as the scale and technique effects arising from the production of homogenous goods. In this paper, the environmental consequences of intra-industry trade are integrated with the environmental effects of inter-industry trade. I propose the following hypotheses about the trade-environment relationship which describe the impact of both intra- and inter-industry on environmental quality.

Hypothesis 1: A positive scale effect contributes positively to the level of emissions, that is, emission is increasing in the level of the scale of production.

Consider an economy with pollution-intensive sectors that produces both homogeneous and differentiated goods. Then the joint-production of pollution implies that the scale of economic activities determines emissions level in the economy. Given technology, an increase (decrease) in the production of dirty goods leads to an increase (decrease) in pollution levels. This is known as the environmental scale effect (Grossman and Krueger 1992; Antweiler et al. 2001). Theory suggests that the scale effect implies a positive relationship between environmental quality and the production of dirty goods. This prediction has been shown to hold in empirical studies (Antweiler et al. 2001). In the current analysis, the direction of the effect of the scale on emissions level is similarly expected to be positive. However, in contrast to past studies, the current study assumes that the trade-induced scale effect represents the expansion of dirty production due to both intra- and inter-industry trade. Hence, the scale effect in the current analysis assumes that an increase (decrease) in the scale of production is not only due to the expansion (contraction) of the production of specialized homogeneous goods with comparative advantage, but that it is also due to an expansion (contraction) of the production of differentiated goods with scale economies. Consistent with theory, the aggregate scale effect of both intra- and inter-industry trade is assumed to be increasing in emissions level.

Note that theory suggests if preferences are CES, then the trade-induced scale effect of intra-industry trade may yield little or no effect on the level of total emission in the domestic economy (Chapter Three). On the other hand, if preferences are represented by a utility function that is non-CES, then the scale effect yields changes in the level of total emission as openness to free trade leads to an expansion in the scale of production (see Chapter Three). The current analysis includes the possibilities of the theoretical predictions of both the non-CES and the CES frameworks.

Hypothesis 2: A negative technique effect contributes negatively to the level of emissions, that is, emission is increasing in emission intensity.

Holding the scale effect and other determinants constant, the technique effect refers to the change in pollution levels due to a change in emission intensity (see Antweiler et al. 2001). In an economy where environmental policy necessitates firms to engage in the reduction of pollution emissions, emission intensity is influenced by abatement technology and the stringency of environmental regulation. Literature suggests that assuming environmental quality is a normal good, income level is tied to emission intensity through the income effect on environmental regulation (see equation (3.34) in Chapter Three). Stricter environmental regulation implies firms will choose to exert greater pollution control which consequently lowers emission intensity. Therefore, the technique effect has a positive relationship with pollution levels. A more stringent (less stringent) environmental regulation leads to lower (higher) is emission intensity and thus lower (higher) pollution emissions. On the other hand, income level which influences environmental policy, is negatively related to pollution levels. An increase (decrease) in income level implies stricter (more lax) policy which leads to lower emission intensity. This implies that holding the scale, selection and composition effects constant, higher income levels leads to lower emission intensity which leads to lower pollution levels. Thus, the current analysis hypothesizes a negative relationship between pollution and income level.

Hypothesis 3: A negative selection effect contributes negatively to the level of emission, that is, emissions level is increasing in the number of firms.

Holding the scale, technique, composition effects and other determinants constant, the selection effect refers to the change in emissions level due to a change in the number of firms that produces differentiated goods. The intra-industry model of pollution suggests a positive empirical relationship between the number of firms and pollution emissions. In the model of monopolistic competition, firms are identical in size and production technology. With trade, consumers choose to consume foreign products resulting in a decrease in the consumption of domestic varieties. The fall in the number of domestic product varieties leads to the exit of unprofitable firms. Assuming the scale and techniques of production remains unchanged, a smaller industry implies less pollution-intensive activities, which means less emission. Hence, everything else equal, openness to trade implies a fall in the number of firms which leads to a fall in emissions level. In other words, emissions level is increasing in the number of firms, ceteris paribus.

However, if preferences are CES, then the trade-induced selection effect is absent. In the CES case, the number of firms is a function of predetermined factors or parameters such that n is fixed (see Chapter Three). The opening of trade does not lead to a change in the number of domestic firms, thus, there is no trade-induced selection effect.

This paper statistically tests for the possibilities of the theoretical predictions of both the general and the CES frameworks. More specifically, if preferences are non-CES, then the selection effect is predicted to have a positive or increasing impact on emissions level. Conversely, if preferences are CES, then the selection effect is neutral, so that the null hypothesis holds.

Hypothesis 4: The composition effect is positively related to the level of emissions, that is, emission is increasing in the intensity of the pollution-intensive factor used in production.

The composition effect is the change in emissions level due to a change in factor intensity used in the production of dirty goods, holding the scale, technique, selection and other determinants constant. Factor intensity in the production of dirty goods is influenced by factors such as the price of factors of production, as well as output and product prices. An increase (decrease) in the factor intensity used in pollution-intensive production should therefore increase (decrease) the level of pollution emissions. In the current study, the composition effect is predicted to have a positive relationship with emissions level (see Antweiler et al. (2001) for evidence to support a positive composition effect). In the open economy context, trade that expands the production of export goods in the pollution-intensive sector leads to a trade-induced composition effect as factors of production shift from other sectors to the export sector. In this case, a positive trade-induced composition effect generates an increase in the aggregate level of emissions.

Hypothesis 5: The level of emissions is decreasing in trade intensity or openness to trade.

The impact of free trade on environmental quality is measured by the variable defined as the ratio of trade volume to GDP, namely, trade intensity. In this analysis, it is postulated that freer trade leads to lower emissions levels. This hypothesis is consistent with findings in Antweiler et al. (2001). There are many reasons why openness to trade may contribute to the improvement of environmental quality. One reason is that greater openness to trade implies an increase in trade flows which leads to an expansion in the scale of overall production. Consequently, income level rises, which implies stricter environmental policy that leads to increased abatement and lower emissions intensity. Further, openness to trade may lead to an inward flow or diffusion of more efficient abatement technology which contributes to reducing emission intensity. Therefore, holding other factors constant, greater openness to trade leads to a negative growth in emissions level.

4.3 Pollution and Intra-industry Trade

In this section, I expand on the decomposition of the environmental effects of intra-industry trade to show the relationship between emissions level and economic factors that define intra-industry trade. I show how the theoretical results in Chapter

Three form the basis of the estimating equations in the empirical analysis. The results in this section complement the decomposition of the environmental effects of inter-industry trade as shown in Antweiler et al. (2001) which I will not replicate in this paper (see section 4.2 on the integration of the environmental concepts of intra- and inter-industry trade).

Although the theory presented in this section is based on the CES framework developed in Chapter Three, the interpretation of the empirical results in this paper will be based on the predictions of both the more general (non-CES) and CES frameworks of intra-industry trade, in addition to the framework of inter-industry trade.

The major advantage of using the CES framework is that it provides tractability in computation and yields closed form solutions. However, one drawback of using the CES assumption is that it suggests fixed output level and fixed number of firms in the open economy. While there is empirical evidence to support the former, there is no clear evidence to support the latter (Head and Rice 1999, 2001). Therefore, literature on intra-industry trade suggests the following. One, the scale of production and the number of firms are fixed and openness of trade does not yield trade-induced scale and selection effects. This result is consistent with the assumption of a CES utility function. Two, and alternatively, trade generates changes in the scale of production and in the number of firms, which lead to trade-induced environmental scale and selection effects. This result is consistent with the assumption of a non- CES, non-homothetic utility function (see Chapter Two). Subsequently, while the analysis adopts the more mainstream CES framework to derive reduced form estimating equations of the intra-industry component, I relax the assumption of CES preferences in interpreting empirical results in order to account for responses that are better explained by different underlying assumptions.

Consider a world which consists of two countries, Home and Foreign (or equivalently, the rest of the world) engaged in the intra-industry trade of dirty goods. Monopolistic competition market structure prevails, characterized by increasing returns technology that is internal to firms (Krugman 1980). Consumers have Dixit-Stiglitz type preferences, where a CES utility function is maximized subject to a budget constraint. Pollution is jointly generated with goods' production. A regulatory authority levies an emission tax to internalize the negative externality associated with the production of pollution. Firms maximize profits taking into account the emission tax imposed by the environmental authority.

4.3.1 Equilibrium Conditions

Generally, a monopolistically competitive industry achieves equilibrium through adjustments in the market price, in the firm's scale of production, and in the number of firms in the industry. Specifically, equilibrium is characterized by two conditions: one, that marginal revenue be equal to (long run) marginal cost $(MR = MC)$; and two, that price equal average revenue which equal average total cost or long run average cost $(p = AR = ATC = LRAC)$.

In the following, I summarize the equilibrium conditions of a CES model of intra-industry trade- and-environment (see Appendix B for details). I omit redefining variable notations in this section. Notations used to denote variables are defined in Chapter Two and Chapter Three, with foreign variables superscripted with asterisks.

The fraction of output allocated towards abatement is given by equation (4.1):

(4.1) $$\theta = 1 - \left(\frac{w\beta}{\tau(\delta - 1)} \right)^{\frac{1}{\delta}}$$

and can be written as

(4.1') $$\theta = \theta(w, \tau, \beta, \delta)$$

The pricing equation is given by equation (4.2):

(4.2) $$p = \frac{1}{\rho}\left(\frac{\delta}{\delta - 1} \right)\left[(w\beta)^{\delta - 1} \tau(\delta - 1) \right]^{\frac{1}{\delta}}$$

or (4.2') $$p = p(w, \tau, \beta, \delta, \rho)$$

The level of output is given by equation (4.3):

(4.3) $$q = \frac{\alpha\rho(\delta - 1)}{\beta\delta(1 - \rho)}$$

so that (4.3') $$q = q(\alpha, \beta, \delta, \rho)$$

The equilibrium number of firms is:

(4.4) $$n = \frac{L\delta(1 - \rho)}{\alpha\left[\delta(1 - \rho) + \rho(\delta - 1) \right]}$$

or (4.4') $$n = n(L, \alpha, \delta, \rho)$$

Consumption of good i in the domestic country is given by:

(4.5) $$c_i = \frac{p_i^{1/(\rho - 1)}}{np^{\rho/(\rho - 1)} + n^* p^{*\rho/(\rho - 1)}} \cdot y$$

that is, (4.5') $$c_i = c_i\left(p, n, p^*, n^*; y, \rho \right)$$

The import of foreign good I is given by equation (4.6):

(4.6) $$m_I = \frac{p_I^{*\,1/(\rho-1)}}{np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}} \cdot y$$

or (4.6') $$m_I = m\left(p, n, p^*, n^*; y, \rho\right)$$

Emission tax rate is given by the following equation (4.7):

(4.7) $$\tau = -\left[\left(\frac{1}{\psi}\right)\varphi\rho^{-1}\left(\frac{w\beta}{(\delta-1)}\right)q\right]^{\frac{1}{1+\rho}}$$

where $$\psi = \left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)^{1-\rho}$$

so that (4.7') $$\tau = \tau\left(\psi; w, \alpha, \beta, \delta, \rho\right)$$

4.3.2 Scale, Technique and Selection Effects

From equation (3.19) in Chapter Three, the relationship between emission level and the scale, technique and selection effects is given by:

(4.8) $$\hat{Z} = \hat{n} + \hat{e} + \hat{q}$$

where $\hat{Z}$ is the percent change in total emission, $\hat{n}$ is the percent change in the number of firms (or equivalently, in the number of product varieties), $\hat{e}$ is the percent change in emission per unit output, and $\hat{q}$ is the percent change in the level of output. Equation (4.8) shows that the impact of intra-industry trade on the environment is measured as the sum of the scale $(\hat{q})$, technique $(\hat{e})$ and selection $(\hat{n})$ effects. The scale effect describes how a change in the scale of production affects emission levels in the economy, holding the technique and selection effects constant. The selection effect describes the change in emission due to a change in the number of product varieties consumed, holding the scale and technique effects constant. The technique effect is the change in emission levels due to a change in emission intensity, holding the scale and selection effects constant.

4.4 Reduced Form Equations

The private demand for pollution is given by equation (4.8) while the supply of pollution is given by equation (4.7). Equation (4.7) can be decomposed into its primitive determinants (see Appendix B), and combining the supply and demand for pollution generates a parsimonious reduced form equation given by:

$$(4.9) \quad \hat{Z} = \Pi_1\hat{n} + \Pi_2\hat{S} + \Pi_3\hat{w} + \Pi_4\hat{n}^* + \Pi_5\hat{p}^* + \Pi_6\hat{L} + \Pi_7\hat{\rho} + \Pi_8\hat{\beta} + \Pi_9\hat{\delta} + \Pi_{10}\hat{\varphi} + \Pi_{11}\hat{\alpha}$$

Equation (4.9) relates emission levels to economic variables. Total emissions is influenced by the number of domestic firms (n), the level of output produced for the purpose of consumption (S), wage which is net income (w), the factor of production in the economy (L), imported product varieties (n^*), the world price level ($\hat{p}^*$), the preference parameter (ρ), the productivity of labor parameter (β), the elasticity of emission with respect to the fraction of output allocated towards consumption (δ), the marginal disutility of pollution (φ), and fixed cost (α).

4.4.1 An Empirical Model of Inter-industry and Intra-industry Trade

In this paper, the estimating equation will take into account the effects of inter-industry trade, in addition to the effects of intra-industry presented in the previous section. OECD countries in the sample are assumed to engage in both intra- and inter-industry trade. This assumption recognizes that countries tend to engage in intra-industry trade with trading partners that are in close geographical proximity and to engage in inter-industry trade with countries that are distant to their geographical borders.

Antweiler et al. (2001) derive a reduced form equation that relates total emissions to economic factors composed of scale, capital intensity or the capital labor ratio (in a two-factor economy), income, the trade friction parameter, world price level, and country type. Their empirical study shows that trade-induced technique and scale effects result in a net reduction in pollution when international trade changes the composition of national output (a composition effect). The significance of the study by Antweiler et al. (2001) is that it develops a formal trade-environment framework which provides theoretical underpinnings of a trade-environment relationship[12].

The analysis in this paper departs from Antweiler et al. (2001) in that it takes into account the environmental effects of both inter- and intra-industry trade. This paper links the effects of intra-industry trade to the effects of inter-industry by integrating the reduced form variables shown in the Antweiler e al. (2001) with the reduced form variables described in the intra-industry trade model in Chapter Three. Hence, the empirical model is a function of four environmental effects, namely, the scale, technique, composition, and selection effects. Note that the inter-industry and intra-industry models overlap in terms of the scale and technique effects and thus these effects will be represented by the same measures in the estimating equation.

To my knowledge, there has not been an empirical study that combines the effects of both intra-industry and inter-industry trade on environmental quality. By controlling

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[12] Antweiler et al. (2001) conclude that freer trade is good for the environment. Their formal framework is based on the traditional trade model where trade is driven by cross-country differentials in relative factor endowments.

for the environmental effects of intra-industry trade, more precise estimation is obtained by preventing an omitted variable, which, if excluded, may produce biased estimates. Moreover, if the selection effect is a significant factor in the data generating process, then its inclusion implies an improvement over, if not a correction to, current econometric specifications which analyzes the relationship between pollution and economic factors without accounting for the selection effect.

Based on the foregoing arguments, the composition effect factor from the Antweiler et al. (2001) trade model is added to the reduced-form equation in equation (4.9). For the purpose of reference, the reduced form derived in Antweiler et al. (2001) is reproduced in following equation (4.10), using the authors' original notations. Equation (4.10) links emission levels $\hat{z}$, to the scale effect, denoted $\hat{S}$, the capital-labor ratio $\hat{\kappa}$, income $\hat{I}$, trade frictions $\hat{\beta}$, the world price levels $\hat{p}^w$, and country type parameter $\hat{T}$ such that:

$$\hat{z} = \pi_1 \hat{S} + \pi_2 \hat{\kappa} - \pi_3 \hat{I} + \pi_4 \hat{\beta} + \pi_5 \hat{p}^w - \pi_6 \hat{T} \tag{4.10}$$

A comparison of equation (4.10) to equation (4.9) indicates that the following economic factors distinguish intra-industry effect from inter-industry trade effects: the number of firms or the number of product varieties available for consumption $\left(n, n^*\right)$, the preference parameter ρ, the emission abatement parameter δ, the labor productivity parameter β, and the price of factor of production w. On the other hand, the two equations overlap in terms of economic factors that represent trade barriers, world price, and income levels.

Combining the reduced form equation obtained in this section with the reduced form equation obtained in Antweiler et al. (2001) yields the following:

$$(4.11) \quad \hat{Z} = \Pi_1\hat{n} + \Pi_2\hat{S} + \Pi_3\hat{w} + \Pi_4\hat{n}^* + \Pi_5\hat{p}^* + \Pi_6\hat{L} + \Pi_7\hat{\rho} + \Pi_8\hat{\beta} + \Pi_9\hat{\delta} + \Pi_{10}\hat{\varphi} + \Pi_{11}\hat{\alpha} + \Pi_{12}\hat{p}^w + \Pi_{13}\hat{\kappa} + \Pi_{14}\hat{\omega} + \Pi_{15}\hat{\vartheta} + \Pi_{16}\hat{T}$$

where p^w denotes world price, κ denotes capital intensity, ω denotes income, ϑ denotes trade friction, and T denotes country type[13].

The selection effect, denoted n, describes the change in emission level due to a change in the number of product varieties consumed, everything else constant. A trade-induced selection effect occurs when the country is exposed to foreign competition which affects a change in the number of domestic firms, or equivalently, in the number of varieties produced domestically. In the open economy, consumers with love-for-variety preferences choose to demand foreign varieties in addition to domestic varieties. Theory suggests a trade-induced increase (decrease) in the number of domestic product varieties or firms leads an increase (decrease) in the level of emission (see Chapter Three).

The scale effect is denoted S in (4.11). It describes the change in emissions level due to a change in the scale of production, holding everything else equal. In this paper, the realization of a trade-induced scale effect comes from two sectors, one, from the intra-industry trade sector and two, from the inter-industry trade sector. The scale effect from each sector is indistinguishable in terms of data as represented by the change in GDP. An expansion in the scale of total production leads to an increase in emissions.

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13 Notations in the Antweiler et al. (2001) may differ from the ones used here.

The technique effect is the change in emission levels due to a change in emission intensity, holding the scale, selection, composition effects and other factors constant. In equation (4.11), the technique effect is represented by a change in wage, w, which is net income in the intra-industry trade sector and in ω, which is income in the inter-industry trade sector. Since the realization of the technique effect from each trade sector is indistinguishable when measured as country-level income, I combine w and ω in equation (4.11) as total income, denoted y. Under the assumption that environmental quality is a normal good, higher income levels imply stricter environmental regulation which leads to lower emission intensity.

The composition effect is the change in emissions level resulting from a change in the capital intensity used in the production. In equation (4.11), capital intensity is denoted as κ. A trade-induced composition effect stems from a change in goods' price which leads to a change in the composition of factor intensity in the inter-industry sector (see Antweiler et al. 2001). Assuming capital is the factor of production used in the pollution-intensive sector, an increase in the level of capital intensity leads to an increase in emissions level.

Note that the preference for product varieties, ρ, the labor productivity, β, the elasticity of emission with respect to the fraction of output allocated towards consumption, δ, fixed cost, α, and the marginal disutility of pollution, φ, are fixed factors in the model. Measures and data for these country-specific effects, namely, α, ρ, β, δ and φ, are not readily available, therefore they are considered as unobserved country parameters in the model.

It is noted that while the scale, technique, selection and composition factors are endogenous variables, emission levels are determined endogenously but recursively[14]. In the model, the scale, technique and selection effects are determined by basic economic factors, predetermined parameters and exogenous variables. Pollution or emissions level itself does not cause any change in the factors that affect the reduced-form variables. For example, a change in the number of firms is determined by changes in factors such as the output level and the level of employment of the labor force but is not determined by a change in emissions level. In other words, there is no simultaneity or feedback between the number of firms and the level of emissions. A change in emissions level does not cause second-order changes in the number of firms, or in the measures for scale and technique effects. Thus, while the variables of scale, the number of firms, real income and pollution tax are set simultaneously in the model, emissions level is set recursively.

4.5 Empirical Strategy

To obtain the estimating equation, theoretical relationships need to be translated into an empirical specification using measures that can be estimated. To do so, data and their sources are discussed in this section.

4.5.1 Measurement and Data Sources

The dependent variable in the proposed estimating equation is the level of emission that prevails in the economy. In this paper, I consider three types of air pollutant that may be used as separate measures of pollution emission: sulfur oxides (SOx),

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14 This assumption is similar to Antweiler et al. (2001).

nitrogen oxides (NOx) and volatile organic compounds (VOC). SOx, NOx and VOC are measured in metric tonnes.

Sulfur oxides (SOx) are produced mainly through the burning of fossil fuels. Sulfur oxides gases are formed when fuels containing sulfur such as coal and crude oil are burned or when gasoline is extracted from oil. Since sulfur is prevalent in ore that contains metals such as aluminum, copper, zinc, lead, and iron, sulfur oxides are also produced in the extraction of metal from ore. Reductions in sulfur oxides emissions are achieved through the implementation of air quality standards, through sulfur dioxide emissions trading programs, from abatement efforts which include the installations of pollution control equipments, and through other control programs that would reduce, for example, the average sulfur content of burned fuels. Sulfur oxides (SOx) are the more widely regulated pollutant among the three pollutants.

Nitrogen oxides or NOx include the highly reactive gasses nitrogen dioxide (NO_2), nitrous acid and nitric acid. In particular, NO_2 is formed from emissions produced in transportation such as cars, trucks and buses, from power plants and off-road equipments. It contributes to the formation of ground-level ozone and fine particle pollution. Nitrogen oxides emissions are mainly regulated through air quality standards set by regulatory authorities.

The third pollutant, volatile organic compounds (VOC), is defined as "any organic compound that participates in atmospheric photochemical reactions except those designated by EPA as having negligible photochemical reactivity" (EPA 2009). Volatile organic compounds (VOC) are emitted from the burning of coal, oil and gasoline. Other sources of VOC include cleaners, paints and solvents. Volatile organic compounds may also be found to contaminate ground and drinking water. While outdoor VOC may be regulated, indoor VOC may not be easily regulated due to the lack of authority in regulating indoor air quality and in collecting information on household products.

The pollutants, sulfur oxides, nitrogen oxides and volatile organic compounds are often used in studies as indicators of environmental quality. Their effects are local in nature, a characteristic that is consistent with the theoretical assumption in this study. Data on the three pollutants, SOx, NOx and VOC, are sourced from OECD Environmental Data for the years 1995-2004. I use the logarithmic transformation of each pollutant to provide a lognormal distribution of the annual country level data as recommended in previous work in this area (see WHO (1984) and Antweiler et al. (2001) on the appropriateness of lognormal distributions).

Data on GDP, GNP in 2000 dollars and other macroeconomic variables is sourced from the Penn World Tables (PWT 6.2) as described by Summers, Heston and Aten (2006), for the years 1995-2004. Gross domestic product per square kilometer (GDP/km^2) measures the scale effect. Gross national product per capita (GNP/L) earned both domestically and abroad[15] measures the technique effect. The technique effect is the effect on emissions level resulting from environmental compliance induced by a change in income level. To avoid high or perfect correlation between GDP and GNP, the difference between the two variables will be used to separate the technique effect from the scale effect. To prevent contemporaneous correlation with GDP, I construct a three-

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[15] Antweiler et al. (2001) use income to measure the technique effect which is replicated in the current analysis.

year moving average of per capita GNP that is lagged one period (see Antweiler et al. 2001).

In equation (4.11), the selection effect of intra-industry trade is represented by the number of firms, n. In theory, the selection effect comes from the change in the number of product varieties or in the number of firms engaged in the production of differentiated goods. Thus, in the data, the selection effect can be represented by two measures: one, by the change in the number of product varieties[16] produced domestically, and two, by the change in the number of domestic firms. Theory suggests the selection effect contributes to a positive (negative) change in pollution levels when there is a trade-induced expansion (contraction) of labor force which leads to an increase (decrease) in the number of domestic firms. Thus, the pollution-trade model suggests a definition of a selection effect that is best defined by firm-level production, that is, by the number of firms that are producing dirty products.[17] Accordingly, I use the number of listed domestic companies to represent the selection effect, sourced from the World Development Indicators (WDI) for the years 1995-2004. Consistent with other measures in the model, the measure for n is in intensive form, that is, it is the number of listed domestic companies per kilometer squared (Companies/km^2).

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[16] Product varieties have been measured in various ways in trade literature, depending on the theoretical context in which varieties are defined. Theoretical tractability imposes restrictive assumptions on which variety may be defined; for example, to allow for the aggregation of price indices or utility functions, it is necessary to use CES or Cobb-Douglas functions in modeling how consumers value variety.

[17] A literal approach of translating theory to data implies that the production of one firm comprises of a single variety. In reality, a firm may produce or export more than one variety in its product line. However, since the objective of the current model is to measure the firm's production of pollution emissions, then, for the purpose of estimating "n", it is sufficient to represent the selection effect by the number of firms engaged in the production of dirty goods or product varieties.

The composition effect is the change in emissions level due to a change in the capital intensity used in production, holding all other factors constant. In the Antweiler et al. (2001) framework, capital is the factor of production used as input in the pollution-intensive industry. Since capital stock data was unavailable for the years of interest in PWT, I construct a capital stock dataset using data on investment sourced from WDI for the years 1995-2004, and based on the method outlined in Leamer (1984 p. 233; see Appendix C for detailed method). Labor data is acquired from PWT so that capital intensity is the ratio of capital stock to labor force (K/L).

Openness to trade is measured by the variable trade intensity, the ratio of imports plus exports to GDP. Trade intensity data is sourced from PWT for the years 1995-2004. Freer trade or trade liberalization is hypothesized to lead to lower emission intensity.

4.5.2 Method

Panel data method is used to estimate the empirical model. The advantage of using panel data is that it provides increased precision in estimation as it allows the analysis of both the spatial and temporal dimensions of units of observation. In contrast to a single cross section analysis, panel data analysis has the advantage of allowing for the dynamics of individual country behavior to be taken into account. In addition, panel data provides consistent estimation of a fixed effects model, where unobserved individual heterogeneity which may be correlated with regressors, can be accounted for. In the case where the unobserved individual heterogeneity is assumed to be distributed independently of the regressors, random effects method of estimation may be used. In this paper, both random and fixed effects estimations are reported. Further, in order to obtain panel-robust statistical inferences, the estimation corrects for both the correlation of model errors over time for given countries and for any heteroskedasticity across countries. A Sargan-Hansen test is performed to determine whether fixed effects are present.

Unobservable Variables

Unobservable parameters such as the parameter of the elasticity of emission intensity with respect to per unit consumption, the disutility of emissions parameter and the preference parameter can be considered as time-invariant country-specific effects represented by the unobserved heterogeneity, denoted as ς_k. It is also noted, as in Antweiler et al. (2001), that common-to-all-countries effects such as changes in the relative price of goods and changes in abatement technologies, may be considered as time-specific effects, denoted as ξ_t. Human error in calculation or tabulation, and machine error in reading pollutant concentrations constitute the idiosyncratic error, υ_{kt}.

To account for the unobservables, an individual effects model for the error term u_{kt} is specified as the following:

(4.12) $$u_{kt} = \xi_t + \varsigma_k + \upsilon_{kt}$$

where ξ_t is a time-specific effect, ς_k is a country specific effect, and υ_{kt} is an idiosyncratic measurement error for country k at time t.

While both fixed effects and random effects estimates are presented, the Sargan-Hansen test allows the determination of the more appropriate estimator between the two.

If country-specific effects contained in the error term are correlated with regressors, then the fixed effects estimator allows for consistent estimation of the model. On the other hand, if the unobserved country-specific heterogeneity is distributed independently of the regressors, then the random effects estimator allows for consistent and efficient estimation of the model. Note that in the case where the fixed effects estimator is appropriate, pooled ordinary least squares (OLS) estimator is inconsistent, while if the random effects estimator is appropriate, then pooled OLS is less efficient.

To capture the effects of time specific, common-to-all-countries variables that are excluded in the model and left unobserved in the error term, I include a set of unrestricted time dummies in the estimating equation.

4.5.3 The Estimating Equation

4.5.3.1 Functional form

A linear representation of pollutant emissions in metric tonnes per squared kilometer at time t and country k is the following model:

$$(4.13)\quad Z_{kt}^{c} = \alpha_0 + \alpha_1 FIRM_{kt} + \alpha_2 SCALE_{kt} + \alpha_3 INC_{kt} + \alpha_4 (KL)_{kt} + \alpha_5 TI_{kt} + G_{kt}^{'}\beta + u_{kt}$$

where FIRM is the country specific number of listed companies per squared kilometer, COM/km^2, SCALE is country-specific GDP/ km^2, INC is GNP/L, TI is trade intensity measured as the import-export ratio to GDP or (X+M)/GDP, and G contains country-specific variables and physical characteristics. Note that the world price and country-type variables are captured in the time-specific error term, ξ_t, and unmeasured economic and physical variables such as the disutility of emissions parameter are captured in the country-specific error term ς_k.

To account for trade-induced environmental effects, I include interacted terms of the variables representing the scale, technique, selection and composition effects with the trade intensity variable.

I specify the following linear model:

(4.14)

$$Z_{kt}^{c} = \alpha_0 + \alpha_1 FIRM_{kt} + \alpha_2 SCALE_{kt} + \alpha_3 INC_{kt} + \alpha_4 (KL)_{kt} + \alpha_5 TI_{kt} +$$
$$\alpha_6 FIRM_{kt} \cdot TI_{kt} + \alpha_7 SCALE_{kt} \cdot TI_{kt} + \alpha_8 INC_{kt} \cdot TI_{kt} + \alpha_9 (KL)_{kt} \cdot TI_{kt} + G_{kt}^{'} \beta + u_{kt}$$

where $FIRM \cdot TI$ is country k's trade intensity interacted with the number of listed domestic companies per squared kilometer, $SCALE \cdot TI$ is country k's trade intensity interacted with gross domestic product per squared kilometer, $INC \cdot TI$ is country k's trade intensity interacted with real income per capita and $KL \cdot TI$ is country k's trade intensity interacted with its capital-to-labor ratio. The vector G contains variables that describes country characteristic which includes the following: population density, *POP*; country k's real income measured relative to the world average, denoted *REL.INC;* country k's number of listed domestic companies per squared kilometer interacted with real income denoted *FIRM.INC*; and time dummies that account for time-specific effects. Equation (4.14) is referred to as Model A in the analysis.

4.5.4 Alternative Functional Form

To account for the possibilities of nonlinearities in responses to the scale, technique and composition effects, I consider an alternative specification by adding squared terms to the linear-in-variables representation of the model in equation (4.14). Non-homotheticities in production or consumption is one reason for a nonlinear response to the environmental effects. Differences in producer prices brought about by cross-country differences in income and in techniques of production may imply that the composition effect should be modeled as a nonlinear function of the capital intensity variable, K/L. These possibilities are consistent with the assumptions of a traditional framework of trade. Therefore, to model nonlinear responses to the environmental effects, I include quadratic measures of the technique and composition effects.

On the other hand, the CES model of pollution and intra-industry trade assumes homotheticity in consumption. This assumption suggests linearity in the response to the scale effect. Further, I maintain that the response to the selection effect is linear in the number of firms. The intra-industry trade framework assumes identical size, preference and production technology across countries. Hence, these imply similarities in income levels. If income levels are similar, then the response to the scale, technique effect and selection variables can be represented by linearity in the data of GDP, income and number of firms to reflect similarities in prices and techniques of production.

To account for the aforementioned possibilities, the following functional form is designated as Model B.

Model B:

$$\begin{aligned}(4.15)\qquad & Z^c_{kt} = \alpha_0 + \alpha_1 FIRM_{kt} + \alpha_2 SCALE_{kt} + \alpha_3 INC_{kt} + \alpha_4 INC^2{}_{kt} + \alpha_5 (KL)_{kt} \\ & + \alpha_6 (KL)^2{}_{kt} + \alpha_7 TI_{kt} + + \alpha_8 FIRM_{kt} \cdot TI_{kt} + \alpha_9 SCALE_{kt} \cdot TI_{kt} \\ & + \alpha_{10} INC_{kt} \cdot TI_{kt} + \alpha_{11} (KL)_{kt} \cdot TI_{kt} + G'_{kt}\beta + u_{kt}\end{aligned}$$

Models A and B sufficiently capture the essential responses to the environmental effects of production and of trade variables in parsimonious specifications.

4.6 Result

4.6.1 Main Result

Tables 4.1, 4.2 and 4.3 present the results of fixed and random effect estimations for three dependent variables, namely, the pollutants sulfur oxides (SOx), nitrogen oxides (NOx) and volatile organic compounds (VOC), respectively.

For each estimation of the SOx, NOx and VOC equations, two econometric models are considered: Models A and B. Model A assumes linearity in all variables and Model B assumes non-linearities in the technique and composition effects variables. I examine the results for each pollutant in turn.

In the next section, sensitivity analysis of the estimations are presented in Tables 4.4, 4.5 and 4.6, each comprising of three estimating models, namely, Model C, Model D and Model E.

Three main results in the analysis warrant attention. One, for each pollutant and for every econometric model A through E, F-tests statistics show that at the 1 percent level of significance, there is evidence to reject the null hypothesis that the variance due to cross-country differences is not different from zero. This result implies the presence of significant country-level effects. Hence, using pooled OLS estimator in the analyses will not be appropriate.

Two, the correlation coefficients between the explanatory variables and unobserved country-level effects range from -0.95 to -0.97 in the fixed effects models of sulfur oxides (SOx), 0.64 to 0.69 in the fixed-effects models of nitrogen oxides (NOx), and -0.51 to -0.57 in the models of volatile organic compounds (VOC). These results suggest high correlation between the regressors and the country level effects. On the other hand, statistically significant coefficient estimates obtained under fixed effects (FE) estimations and under random effects (RE) estimations are nearly identical. Hence, I use the Sargan-Hansen test to determine the appropriateness of using fixed effect (FE) estimator versus random effect (RE) estimator, with cluster-robust standard errors. The Sargan-Hansen test statistics, shown in Tables 4.1 through 4.6, are statistically significant at the 1 percent level of significance which imply we can reject the null hypothesis that the additional orthogonality condition imposed by the RE estimator is valid. These results imply strong evidence to suggest that unobserved country-level heterogeneity is correlated with regressors. Hence, in all models considered, there is evidence to suggest that estimates generated by FE estimators are consistent estimates, whereas estimates generated in the RE models are not. Therefore, in describing the regression results in the following section, I focus only on estimates based on the FE models.

Finally, the interaction terms of each of the environmental variable and the trade intensity variable use demeaned data which subtract the sample mean of each variable from its respective data values. Therefore, the interpretation of the coefficient estimates of the trade-induced scale, technique, selection and composition effects variables are made at the mean value of the trade intensity variable[18]. In other words, coefficient estimates of trade-induced environmental effects are calculated for the "average trading country" defined as the country whose level of trade intensity is equal to the sample mean.

4.6.1 *Sulfur Oxides* (SOx) *and the Selection, Scale, Technique and Composition Effects*

Table 4.1 shows that in the Models A an B, there is a positive relationship between the selection effect variable, represented by the number of listed companies per squared kilometer (Companies/ km^2), and the dependent variable, sulfur oxides emissions (SOx). Estimates are statistically significant for the coefficients on the selection effect variables which do not vary greatly in magnitudes in the estimates of both Model A and Model B. In Model B, evidence suggests that holding other factors constant, a unit change in the number of domestic companies per squared kilometer results in approximately 73 percent change in the level of sulfur oxides per squared kilometer (see Appendix C for calculation details). In Model A, the percentage change in sulfur oxides is 57 percent. The direction of the effect of Companies/ km^2 on sulfur oxides emissions is positive, consistent with the theoretical prediction that an increase (decrease) in the number of firms leads to an increase (decrease) in the level of emissions.

Next, the environmental effect of scale is represented by gross domestic product per kilometer square (GDP/km^2) in Model A and Model B. Estimates of the semi-

18 See Wooldridge (2003) pp. 194-195.

Table 4.1: Estimation Results of Models A and B - Sulfur Oxides (SOx)

Dependent Variable: Log of Sulfur Oxides per sq km

Estimation Method:	Fixed Effects		Random Effects	
Model Specification:	A Levels Only	B	A Levels Only	B
Variable/Column:	(1)	(2)	(3)	(4)
Companies/ km^2	0.501* (0.277)	0.548** (0.260)	0.587** (0.248)	0.605** (0.251)
GDP/km^2	0.320** (0.129)	0.318** (0.125)	-0.124 (0.121)	0.108 (0.120)
Lagged per capita income (INC)	-0.184** (0.073)	-0.411** (0.187)	-0.117* (0.069)	-0.056 (0.200)
Lagged per capita income squared		0.059 (0.044)		-0.013 (0.046)
Capital abundance (K/L)	-0.333 (0.197)	0.066 (0.259)	-0.385*** (0.139)	-0.262 (0.184)
(K/L) Squared		-0.036*** (0.013)		-0.010 (0.011)
Trade Intensity (TI=X+M/GDP)	-0.026*** (0.007)	-0.026*** (0.006)	-0.021*** (0.006)	-0.021*** (0.006)
Relative Income	0.009 (0.007)	0.009 (0.006)	0.009 (0.006)	0.010* (0.006)
Population Density	-0.333*** (0.096)	-0.379*** (0.102)	0.032 (0.025)	0.036 (0.027)
TI x Companies/ km^2	-0.013** (0.005)	-0.012** (0.005)	-0.007 (0.005)	-0.006 (0.005)
TI x GDP/ km^2	-0.0001 (0.002)	0.0002 (0.002)	-0.002* (0.001)	-0.002* (0.0001)
TI x Per capita Income	-0.007** (0.003)	-0.008*** (0.002)	-0.006*** (0.002)	-0.006*** (0.002)
TI x (K/L)	-0.001 (0.002)	-0.0001 (0.002)	-0.001 (0.002)	-0.0009 (0.002)
Companies x Per capita Income	-0.203* (0.103)	-0.231** (0.095)	0.181** (0.088)	-0.197** (0.091)
Intercept	-0.689 (0.722)	-0.919 (1.916)	-4.714*** (0.973)	-5.117*** (1.040)
Observations	211	211	211	211
Group	23	23	23	23
R^2 - within	0.7731	0.7826	0.7559	0.7603
R^2 - between	0.2290	0.2616	0.7785	0.7588
R^2 - overall	0.2109	0.2412	0.8054	0.7915
Sargan-Hansen Test/ χ^2 (df)			1609***	572***
LR test/ χ^2 (df)	8.93***			

***Significance at the 99-percent confidence level.
**Significance at the 95-percent confidence level.
*Significance at the 90-percent confidence level.
Note: Standard errors in parentheses are cluster-robust.

elasticities of scale in both models show there is a statistically significant positive relationship between GDP/km^2 and the dependent variable, sulfur oxides. Coefficient estimates indicate that holding other factors equal, a unit increase in GDP/km^2 leads to a 38 percent increase in sulfur oxides emissions for Model A and a 37 percent increase in sulfur oxides for Model B.

The technique effect is represented by the lagged per capita income (*INC*) variable and the lagged per capita income squared (INC^2)[19]. Regression estimates for Model A and Model B suggest that there is a negative relationship between income per capita and sulfur oxides emissions. In Model B, a 1 unit increase in income level leads to a 51 percent decrease in sulfur oxides emissions level, while in Model A, it leads to a 20 percent decrease, holding other factors constant. The coefficient estimates for the quadratic term of lagged per capita income in Model A and Model B are not statistically significant.

There are two observations to make of the effect of income on sulfur oxides. First, OECD countries are comprised of mostly developed nations whose incomes per capita are greater than the per capita incomes of developing countries. The inverted-U shape of the Environmental Kuznets Curve (EKC) has a turning point of approximately $8,000 to $10,000 per capita income (Grossman and Krueger 1993) which is below the sample mean of per capita income of OECD countries in this analysis (see summary statistics of data in Appendix C). The EKC is the postulated relationship between environmental quality and income per capita; the inverted-U shape of the EKC indicates that at the early

[19] This functional form is consistent with the Environmental Kuznets Curve (EKC) hypothesis, postulated by Grossman and Krueger (1993).

stage of development, pollution levels increases with the increase in income per capita. The curve reaches a peak and descends after the turning point, indicating that in the later stages of development, as income per capita continues to rise, pollution levels decrease as countries impose stricter environmental regulations to obtain higher environmental quality, a normal good. Therefore, for the more affluent and developed economies, an increase in income leads to stricter environmental policy which then leads to lower emission intensity. Thus, the technique effect is manifested as a negative relationship between income per capita and emissions levels, as indicated by the negative direction of the effect of income on sulfur oxides . A second observation is that the coefficient estimate of the level-form of INC is statistically significant but the coefficient estimate of the squared INC^2 is not statistically significant. These results indicate that linearity in the income variable generates statistically significant estimates while non-linearity generates statistically insignificant estimates. The former is consistent with the assumption of a homothetic utility function where the shares of income spent on consumption goods are constant. Further, in the theoretical framework, a fixed fraction of output or resources is allocated towards abatement activity where pollution production is constant returns to scale. Thus, a change in the stringency of environmental policy implies a linear change in abatement levels. This provides an explanation of the statistically significant estimates of the technique effect in the linear or level form of the income variable. Thus, the realization of income data seems to suggest that the assumption of homotheticity, consistent with intra-industry trade, is more relevant in capturing responses to the technique effect, as opposed to an assumption of non-homotheticity.

The composition effect variable is represented by capital intensity. In Model A which assumes linearity in all variables, the coefficient estimate of capital intensity is not statistically significant at the conventional levels of significance. In Model B, which assumes a quadratic functional form of the composition effect variable, the semi elasticity estimates of composition effect is statistically significant at the 5 percent levels. This result indicates strong evidence to suggest that a 1 unit increase in capital intensity leads to a 38 percent increase in sulfur oxides emissions, calculated at the mean value of capital intensity.

Interestingly, in both Models A and B, the coefficient estimates of the capital intensity variables measured in level forms are not statistically significant. A test of the joint significance of the variables capital intensity (K/L) and capital intensity-squared (K/L-squared) generates an F-test statistic that is statistically significant at the 1 percent significance level. This result suggests we can reject the null hypothesis that the model which excludes the variables K/L and K/L-squared is correctly specified relative to the full model. Therefore, the evidence suggests that a quadratic functional form captures the responses to the composition effect on pollution. This is consistent with the assumption of non-homothetic production, under the theoretical proposition that the impact of capital accumulation on the emission of sulfur oxides depends on the techniques of productions with varying income levels across countries (see Antweiler et al. 2001).

The impact of freer trade or openness to trade on environmental quality is estimated by the effect of a change in the trade intensity variable on the change in emissions level. In both Models A and B, coefficient estimates on the trade intensity variables are statistically significant at less than 1 percent level of significance. These results indicate evidence to suggest that a 1 unit change in the ratio of the volume of trade to GDP leads to approximately 2.6 percent decrease in the levels of sulfur oxides emissions. The negative direction of the effect of trade intensity on emissions level conforms to theoretical prediction which suggests that greater openness to trade or increased trade liberalization is beneficial to the environment.

I use a likelihood ratio (LR) test to evaluate the goodness of fit of the nested models A and B. Results show that the linear-in-variables and more restricted model A has lesser fit compared to the more general Model B. A significant LR-test statistic shows that the restrictions on Model A are rejected by the data. One explanation for this result is that for the countries in the sample, consumption or production is non-homothetic such that the response to the composition effect implies that capital accumulation generates non-linear effects on the composition of the economy. Hence, for the pollutant sulfur oxides, the specification (LR-test) result indicates that greater emphasis should be given to estimates generated in Model B.

4.6.2 *Nitrogen Oxides* (NOx) *and the Selection, Scale, Technique and Composition Effects*

Table 4.2 shows the responses of changes in the selection, scale, technique and composition effects on the level of nitrogen oxides (NOx). Fixed effects estimations indicate that for the Models A and B, there is a positive relationship between the selection effect variable, represented by the number of listed companies per squared kilometer (Companies/ km^2), and the dependent variable, nitrogen oxides emissions.

Table 4.2: Estimation Results of Models A and B - Nitrogen Oxides (NOx)

Estimation Method:	Fixed Effects		Random Effects	
Model Specification:	A Levels Only	B	A Levels Only	B
Variable/Column:	(1)	(2)	(3)	(4)
Companies/ km^2	0.225**	0.257***	0.382***	0.374***
	(0.085)	(0.090)	(0.090)	(0.090)
GDP/ km^2	0.107	0.087	0.110*	0.084
	(0.072)	(0.068)	(0.061)	(0.053)
Lagged per capita income	-0.060	-0.011	-0.047	0.034
	(0.049)	(0.114)	(0.040)	(0.089)
Lagged per capita income		-0.011		-0.019
squared		(0.021)		(0.019)
Capital abundance (K/L)	0.006	0.122	-0.048	0.070
	(0.067)	(0.084)	(0.045)	(0.065)
(K/L) Squared		-0.010		-0.009
		(0.006)		(0.006)
Trade Intensity	-0.004	-0.004	-0.002	-0.002
(TI=X+M/GDP)	(0.003)	(0.003)	(0.003)	(0.003)
Relative Income	-0.006**	-0.006**	0.002	0.0009
	(0.003)	(0.003)	(0.004)	(0.003)
Population Density	0.006	0.010	0.045***	0.052***
	(0.057)	(0.059)	(0.011)	(0.010)
TI x Companies/ km^2	-0.005**	-0.004	-0.001	-0.0005
	(0.002)	(0.003)	(0.002)	(0.002)
TI x GDP/ km^2	0.0002	0.0003	-0.0003	-0.0002
	(0.0008)	(0.001)	(0.0007)	(0.001)
TI x Per capita Income	-2.55e-06	-0.0004	-0.00002	-0.0002
	(0.002)	(0.002)	(0.001)	(0.001)
TI x (K/L)	-0.001	-0.0004	-0.0004	-0.0004
	(0.001)	(0.001)	(0.001)	(0.001)
Companies x Per capita	0.032	0.011	0.020	-0.005
Income	(0.035)	(0.035)	(0.026)	(0.027)
Intercept	-6.473***	-6.843***	-6.981***	-7.369***
	(0.784)	(0.848)	(0.382)	(0.336)
Observations	211	211	211	211
Group	23	23	23	23
R^2 - within	0.6035	0.6170	0.5745	0.6001
R^2 - between	0.6952	0.7047	0.7915	0.7833
R^2 - overall	0.7397	0.7685	0.8037	0.8007
Sargan-Hansen Test/ χ^2 (df)			2783***	3924***
LR Test/ χ^2 (df)	7.33**	0.02		

***Significance at the 99-percent confidence level.
**Significance at the 95-percent confidence level.
*Significance at the 90-percent confidence level.
Note: Standard errors in parentheses are cluster-robust.

Statistically significant coefficient estimates of Companies/km^2 at the 99-percent confidence levels provide strong evidence to suggest that, holding other factors constant, a 1 unit change in the number of domestic companies per squared kilometer leads to an approximately 25 percent change in the level of nitrogen oxides per squared kilometer in Model A and approximately 29 percent in Model B. The direction of effect of the selection variable on emissions level is positive, consistent with the theoretical prediction that an increase (decrease) in the number of firms leads to an increase (decrease) in the level of emissions.

Coefficient estimates of the other environmental effects namely, the scale, technique and composition effects are not statistically significant in models A or B. Similarly, estimates of the effects of trade intensity and other country-specific variables are not statistically significant where p-values indicate we fail to reject the null hypothesis at the conventional levels of significance.

Interestingly, except for the coefficient estimate of interacted term between the selection effect variable and the trade intensity variable (that is, GDP/km^2 x TI), evidence suggests that all other coefficient estimates of interacted terms in the three models are statistically not different from zero. Meanwhile, the Relative Income variable in both models A and B is statistically significant at the 5 percent level of significance. These results seem to suggest that for the pollutant nitrogen oxides, the scale of production, the emission intensity of pollution and the composition of capital to labor ratio do not affect emissions level. While the selection effect is robust in the two models, the neutrality of the scale, technique and composition effects may be explained by the proposition in new or intra-industry trade theory that assumes CES preferences (see Chapter Two). That is, the findings: one, that the selection effect is statistically significant in the level form and in the interaction forms, and, two, that the scale and technique effects are not statistically significant; would suggest that trade-induced environmental-selection effect exists but that environmental- scale effect and technique effects are absent. These results are consistent with evidence found in trade literature which supports a trade-selection effect, but not a trade-scale effect (see Head and Rice 1999, 2001).

4.6.3 *Volatile Organic Compounds (VOC) and the Selection, Scale, Technique and Composition Effects*

Table 4.3 shows the estimates of the selection and scale effects which are statistically significant in Models A and B at the 1 percent level of significance. Both the selection and scale effects have positive relationship to the emissions levels of volatile organic compounds (VOC). A 1 unit increase in the number of listed companies per square kilometer (Companies/ km^2) leads to 64 percent increase in volatile organic compounds emissions in Model A, and 68 percent in Model B. Coefficient estimates of the scale effect in the linear-in- variables Model A and the main Model B indicate strong evidence to suggest that a 1 unit increase in GDP/km^2 leads to 14 and 12 percent increase in the level of volatile organic compounds emissions, respectively.

Estimates for both the technique and the composition effects in the models A and B are not statistically significant at conventional levels. Thus, we fail to reject the null hypotheses that the coefficient estimates of the income (*INC*) and capital intensity (*K/L*) variables are equal to zero. One possible explanation for the absence of a technique effect is that a major proportion of volatile organic compounds emissions may not be subjected

Table 4.3: Estimation Results of Models A and B - Volatile Organic Compounds (VOC)

Estimation Method:	Fixed Effects		Random Effects	
Model Specification:	A Levels Only	B	A Levels Only	B
Variable/Column:	(1)	(2)	(3)	(4)
Companies/ km^2	0.497***	0.517***	0.520***	0.537***
	(0.054)	(0.063)	(0.055)	(0.065)
GDP/ km^2	0.129***	0.112***	0.145***	0.131***
	(0.032)	(0.033)	(0.040)	(0.044)
(GDP/ km^2) Squared				
Lagged per capita income	-0.008	0.086	0.0003	0.057
	(0.044)	(0.116)	(0.040)	(0.097)
Lagged per capita income		-0.019		-0.013
squared		(0.022)		(0.019)
Capital abundance (K/L)	-0.037	0.003	-0.046	0.015
	(0.041)	(0.098)	(0.043)	(0.081)
(K/L) Squared		-0.003		-0.005**
		(0.007)		(0.006)
Trade Intensity (TI=X+M/GDP)	-0.004**	-0.004*	-0.004***	-0.004
	(0.002)	(0.002)	(0.002)	(0.001)
Relative Income	0.001	-0.002	0.001	0.002
	(0.004)	(0.004)	(0.003)	(0.003)
Population Density	0.067	0.077	0.031**	0.035***
	(0.055)	(0.061)	(0.013)	(0.012)
TI x Companies/ km^2	0.001	0.002	0.001	0.002
	(0.002)	(0.002)	(0.002)	(0.002)
TI x GDP/ km^2	-0.0005	-0.0004	-0.0003	-0.0003
	(0.001)	(0.001)	(0.001)	(0.0006)
TI x Per capita Income	-0.003*	-0.002	-0.002	0.002
	(0.001)	(0.002)	(0.001)	(0.001)
TI x (K/L)	-0.003***	-0.002***	-0.002***	-0.002***
	(0.001)	(0.001)	(0.001)	(0.0008)
Companies x Per capita Income	-0.090**	0.076	0.081**	0.068
	(0.040)	(0.047)	(0.040)	(0.046)
Intercept	-7.538***	-7.821***	-7.115***	-7.366***
	(0.717)	(0.699)	(0.252)	(0.246)
Observations	211	211	211	211
Group	23	23	23	23
R^2 - within	0.8220	0.8249	0.8209	0.8238
R^2 - between	0.6507	0.6495	0.6796	0.6836
R^2 - overall	0.6510	0.6500	0.6804	0.6862
Sargan-Hansen Test/ χ^2 (df)			2370***	8704**
LR Test/ χ^2 (df)	3.46**			

***Significance at the 99-percent confidence level.
**Significance at the 95-percent confidence level.
*Significance at the 90-percent confidence level.
Note: Standard errors in parentheses are cluster-robust.

to environmental regulation. Indoor VOCs, for example, are outside the purview of the regulatory authority; hence, regulation compliance is not enforceable. In the United States of America, sources of volatile organic compounds (VOC) emissions comes mainly from road vehicles, solvent use, fires and non-road equipment, which in the year 2002 makes up seventy five percent of total volatile organic compounds emissions (EPA 2009). The absence of a composition effect on volatile organic compounds emissions may be explained by the possibility that changes in the level of capital intensity in pollution intensive production do not affect volatile organic compounds. This may be the case if the production of volatile organic compounds is not capital-intensive. That is, shifts in the level of the use of capital in the VOC-intensive sectors have no effect on the levels of volatile organic compounds emissions.

For the effect of openness to trade, coefficient estimates of the variable trade intensity are statistically significant at the 5 percent level of significance in Models A and at the 10 percent level in Model B. There is evidence suggests that a 1 unit increase in trade intensity leads to 0.4 percent decrease in volatile organic compounds emissions in Models A and B. These findings substantiate the prediction of a negative relationship between trade intensity and emissions level. The results are consistent with findings in the cases of sulfur oxides and nitrogen oxides.

Estimates for the trade-induced environmental effects for volatile organic compounds, namely, the trade-induced scale, technique, composition and selection effects are represented by the respective variables interacted with the trade-intensity variable. In the linear-in-variables Model A, with the exception of the selection effect, estimates of the trade-induced technique, composition and selection effects are statistically significant at the conventional level of significance. In Model B, the sole variable with statistically significant coefficient estimate is the trade-induced composition effect. These results suggest that the one common statistically significant trade-induced effect in the two models is the composition effect. However, when calculated for the average country in the sample, the composition effect does not lead to any change in the emissions level of volatile organic compounds. This result is consistent with the result of neutral linear-form composition effect in models A and B.

4.7 Alternative Specification

In this section, I present three alternative econometric models to the main Model B to test the robustness of the results obtained in the previous section. The three alternative specifications are: Model C which specifies an estimating equation that is absent of the selection effect, Model D which does not include any interaction terms, and Model E which includes foreign direct investment as an additional trade variable. I discuss the results in Tables 4.3, 4.4 and 4.5 for each Model C, D and E in turn. I begin with estimates of Model C, followed by Model D, and finally with Model E.

Regressions of the Model C, which excludes the selection effect variable Companies/ km^2, generate mostly statistically insignificant estimates for the three pollutants sulfur oxides, nitrogen oxides and volatile organic compounds.

For the pollutant sulfur oxides, fixed effects estimation of Model C shows one statistically significant coefficient estimate at the 1 percent level, for the variable trade intensity. In the cases of nitrogen oxides and volatile organic compounds, the sole significant estimate is for the variable population density. An explanation for the lack of

Table 4.4: Sensitivity Analysis for Sulfur Oxides (SOx)

Dependent Variable: Log of Sulfur Oxides per sq km

Estimation Method:	Fixed Effects			Random Effects		
Model Specification:	C	D	E	C	D	E
	No Selection	No Interaction	FDI	No Selection	No Interaction	FDI
Variable/Column:	(1)	(2)	(3)	(4)	(5)	(6)
Companies/ km^2		0.808***	0.439*		0.688***	0.591**
		(0.102)	(0.145)		(0.230)	(0.264)
GDP/ km^2	-0.282	0.177	0.305***	-0.160	-0.130	0.100
	(0.130)	(0.123)	(0.117)	(0.238)	(0.089)	(0.116)
Lagged per capita	-0.004	-0.426*	-0.464**	0.038	-0.030	-0.033
income	(0.226)	(0.188)	(0.177)	(0.259)	(0.211)	(0.207)
Lagged per capita	0.005	0.112	0.069	-0.009	0.008	-0.019
income squared	(0.054)	(0.046)	(0.042)	(0.060)	(0.054)	(0.048)
Capital abundance	-0.062	0.462*	0.110	-0.221	-0.101	-0.307*
(K/L)	(0.206)	(0.158)	(0.157)	(0.218)	(0.004)	(0.173)
(K/L) Squared	-0.026	-0.066**	-0.039***	-0.013	-0.017	-0.007
	(0.017)	(0.013)	(0.013)	(0.014)	(0.020)	(0.012)
Trade Intensity	-0.018***	-0.017***	-0.027***	-	-0.011***	-
(TI=X+M/GDP)	(0.003)	(0.002)	(0.003)	0.018***	(0.040)	0.021***
				(0.007)		(0.007)
Relative Income	0.017	-0.023	0.011	0.019**	0.027***	0.010*
	(0.017)	(0.015)	(0.013)	(0.009)	(0.010)	(0.006)
Population Density	0.206	-0.293**	-0.401***	0.112	0.090***	0.039
	(0.134)	(0.127)	(0.113)	(0.069)	(0.036)	(0.026)
TIxCompanies/ km^2			-0.015**			-0.007
			(0.004)			(0.006)
TI x GDP/ km^2	-0.001		0.001	-0.001		-0.002*
	(0.001)		(0.001)	(0.002)		(0.001)
TI x Per capita	-0.001		-0.008***	-0.001		-0.006*
Income	(0.002)		(0.002)	(0.002)		(0.002)
TI x (K/L)	-0.002		0.0001	-0.002		-0.001
	(0.001)		(0.001)	(0.002)		(0.002)
Companies x Per			-0.239**			-0.203**
capita Income			(0.068)			(0.095)
Foreign Direct			-0.009***			-0.007**
Investment			(0.002)			(0.003)
Intercept	-6.56**	-3.67*	-0.54	-5.34***	-6.63***	-5.02***
	(1.609)	(1.372)	(1.333)	(1.217)	(0.639)	(1.025)
Observations	211	211	210	211	211	210
Group	23	23	23	23	23	23
R^2 - within	0.6312	0.7021	0.8002	0.6276	0.6643	0.7702
R^2 - between	0.6203	0.2446	0.2779	0.6729	0.7120	0.7586
R^2 - overall	0.6255	0.2200	0.2610	0.6811	0.7366	0.7894

Table 4.4: Sensitivity Analysis for Sulfur Oxides (SOx) Continued

Sargan-Hansen Test/ χ^2 (df)			525***	714***	7626***
LR Test/ χ^2 (df)	111.45***	66.44***			

***Significance at the 99-percent confidence level.
**Significance at the 95-percent confidence level.
*Significance at the 90-percent confidence level.
Note: Standard errors in parentheses are cluster-robust.

evidence to support the prediction of theory in these cases is that, in excluding the selection variable, the estimation is not controlling for a theoretically relevant and important variable that belongs in the estimating equation. The omission of the selection variable leads to misspecification and omitted variable biases. The effects of misspecification and variable omission are shown by comparing the results obtained in Model C with the results obtained in the main Model B. Model B includes the selection effect variable, Companies/ km^2.

When the selection variable, Companies/ km^2, is added, thus generating the main model that is Model B, all other coefficient estimates of the theoretically relevant variables, namely, the scale, technique and composition variables, which were previously not statistically significant in Model C, are statistically significant in Model B. In addition, the estimates in Model B have the correct signs in terms of the direction of effects on the dependent variables, thus conforming to theoretical predictions postulated in both the inter-and intra-industry trade frameworks. These results are consistent with findings in past empirical studies.

Table 4.5: Sensitivity Analysis for Nitrogen Oxides (NOx)

Dependent Variable: Log of Nitrogen Oxides per sq km

Estimation Method:	Fixed Effects			Random Effects		
Model Specification:	C No Selection	D No Interaction	E FDI	C No Selection	D No Interaction	E FDI
Variable/Column:	(1)	(2)	(3)	(4)	(5)	(6)
Companies/ km^2		0.360***	0.246**		0.365***	0.321***
		(0.039)	(0.066)		(0.051)	(0.090)
GDP/ km^2	-0.185	0.074*	0.086	-0.113	0.049***	0.074
	(0.054)	(0.047)	(0.053)	(0.126)	(0.018)	(0.050)
Lagged per capita income	0.122	-0.009	-0.016	0.066	0.015	0.025
	(0.095)	(0.072)	(0.080)	(0.117)	(0.078)	(0.090)
Lagged per capita income squared	-0.039	-0.008	-0.010	-0.027	-0.014	-0.017
	(0.023)	(0.018)	(0.019)	(0.030)	(0.022)	(0.019)
Capital abundance (K/L)	0.098	0.200*	0.130	0.115	0.146	0.089
	(0.086)	(0.061)	(0.071)	(0.113)	(0.096)	(0.065)
(K/L) Squared	-0.008	-0.017	-0.011*	-0.010	-0.014	-0.009
	(0.007)	(0.005)	(0.006)	(0.009)	(0.009)	(0.006)
Trade Intensity (TI=X+M/GDP)	-0.0003	-0.001	-0.004	-0.001	-0.001	-0.003
	(0.001)	(0.001)	(0.001)	(0.004)	(0.001)	(0.003)
Relative Income	-0.002	-0.003	-0.005*	0.002	0.001	-0.001
	(0.007)	(0.006)	(0.006)	(0.004)	(0.003)	(0.003)
Population Density	0.226**	0.024	0.008	0.107***	0.060***	0.054***
	(0.056)	(0.049)	(0.052)	(0.042)	(0.013)	(0.011)
TI x Companies/ km^2			-0.004			-0.002
			(0.002)			(0.003)
TI x GDP/ km^2	0.0004		0.0004	0.001		-0.00004
	(0.0006)		(0.001)	(0.001)		(0.0007)
TI x Per capita Income	0.0001		-0.0004	-0.00005		-0.0002
	(0.0008)		(0.001)	(0.002)		(0.002)
TI x (K/L)	-0.0006		-0.0004	-0.001		-0.0004
	(0.0005)		(0.0004)	(0.001)		(0.001)
Companies x Per capita Income			0.011			0.009
			(0.031)			(0.029)
Foreign Direct Investment			-0.001*			-0.001
			(0.001)			(0.001)
Intercept	-8.76***	-7.42***	-6.82***	-7.46***	-7.67***	-7.36***
	(0.675)	(0.528)	(0.606)	(0.509)	(0.321)	(0.377)
Observations	211	211	210	211	211	210
Group	23	23	23	23	23	23
R^2 - within	0.4037	0.5948	0.6191	0.3869	0.5896	0.6103
R^2 - between	0.6489	0.7424	0.6783	0.6483	0.7715	0.7619
R^2 - overall	0.6508	0.7895	0.7535	0.6529	0.7931	0.7841
Sargan-Hansen Test/ χ^2 (df)				2066***	2127***	1.8e+06***
LR Test/ χ^2 (df)	93.44***	11.93**				

Table 4.5: Sensitivity Analysis for Nitrogen Oxides (NOx) Continued

***Significance at the 99-percent confidence level.
**Significance at the 95-percent confidence level.
*Significance at the 90-percent confidence level.
Note: Standard errors in parentheses are cluster-robust.

Therefore, the results imply that the omission of a relevant variable, Companies/ km^2 which is the selection effect variable, leads to the serious problem of wrongly specified regression models. The consequences of misspecification errors due to the correlation between the explanatory variable and the error term are biased estimates of coefficients.

In Model D, interaction terms are dropped from the main model specification. In the model for sulfur oxides (SOx), responses to the scale, technique, selection and trade intensity effects are statistically significant at conventional levels. However, the response to the composition effect is not statistically significant. In the case of nitrogen oxides (NOx), coefficient estimates of the scale, selection and composition effects are statistically significant, but the coefficient estimate of the technique effect is not statistically significant. Finally, in the case of volatile organic compounds (VOC), only the estimates of the scale, selection and relative income effects are statistically significant.

Because Model D excludes the interaction terms, these results may be interpreted as estimates of the environmental effects on pollution in the autarky case. Hence, in model D, trade-induced effects are not estimated. Consequently, responses to environmental effects that are fully or partly explained by trade are not captured in the coefficient estimates at autarky levels.

Table 4.6: Sensitivity Analysis for Volatile Organic Compounds (VOC)

Dependent Variable: Log of Volatile Organic Compounds per sq km

Estimation Method:	Fixed Effects			Random Effects		
Model Specification:	C	D	E	C	D	E
	No Selection	No Interaction	FDI	No Selection	No Interaction	FDI
Variable/Column:	(1)	(2)	(3)	(4)	(5)	(6)
Companies/ km^2		0.470***	0.524***		0.478**	0.539***
		(0.055)	(0.063)		(0.046)	(0.065)
GDP/ km^2	-0.266	0.066	0.112***	-0.158	0.066**	0.132***
	(0.242)	(0.052)	(0.033)	(0.219)	(0.033)	(0.045)
Lagged per capita income	0.175	-0.106	0.089	0.067	-0.093	0.062
	(0.166)	(0.098)	(0.116)	(0.143)	(0.096)	(0.097)
Lagged per capita income squared	-0.047	0.017	-0.020	-0.025	0.013	-0.014
	(0.040)	(0.025)	(0.022)	(0.035)	(0.025)	(0.019)
Capital abundance (K/L)	-0.017	0.259	0.001	0.045	0.217	0.124
	(0.165)	(0.164)	(0.099)	(0.153)	(0.143)	(0.084)
(K/L) Squared	-0.001	-0.023**	-0.003	-0.006	-0.019**	-0.005
	(0.013)	(0.010)	(0.008)	(0.011)	(0.009)	(0.006)
Trade Intensity (TI=X+M/GDP)	-0.001	0.001	-0.003*	-0.002	0.001	-0.004**
	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)
Relative Income	0.006	0.007*	-0.002	0.007	0.008**	0.002
	(0.007)	(0.004)	(0.004)	(0.005)	(0.004)	(0.003)
Population Density	0.324**	0.050	0.079	0.120*	0.054***	0.037**
	(0.149)	(0.059)	(0.061)	(0.066)	(0.021)	(0.012)
TI x Companies/ km^2			0.002			0.002
			(0.002)			(0.002)
TI x GDP/ km^2	0.001		-0.0005	0.001		-0.0003
	(0.001)		(0.0008)	(0.001)		(0.0006)
TI x Per capita Income	0.001		-0.002	0.001		0.002
	(0.002)		(0.0002)	(0.002)		(0.002)
TI x (K/L)	-0.002		-	-0.002		-
	(0.001)		0.002***	(0.001)		0.002***
			(0.001)			(0.001)
Companies x Per capita Income			-0.077			0.070
			(0.047)			(0.047)
Foreign Direct Investment			-0.0005			0.0005
			(0.0008)			(0.0008)
Intercept	-9.54***	-8.06***	-7.86***	-7.35***	-8.02***	-7.39***
	(1.447)	(0.556)	(0.702)	(0.546)	(0.461)	(0.238)
Observations	211	211	210	211	211	210
Group	23	23	23	23	23	23
R^2 - within	0.6295	0.7577	0.8252	0.6048	0.7569	0.8242
R^2 - between	0.5351	0.6728	0.6496	0.5105	0.6840	0.6809
R^2 - overall	0.5276	0.6876	0.6514	0.5049	0.6940	0.6849

Table 4.6: Sensitivity Analysis for Volatile Organic Compounds (VOC) Continued

Sargan-Hansen Test/ χ^2 (df)				1520***	2732***	1.5e+06***
LR Test/ χ^2 (df)	158.6***	68.5***				

***Significance at the 99-percent confidence level.
**Significance at the 95-percent confidence level.
*Significance at the 90-percent confidence level.
Note: Standard errors in parentheses are cluster-robust.

However, and interestingly, note that for all the three pollutants, coefficient estimates of the selection effect variable are statistically significant at the 1 percent level.

The above findings suggest the following. One, there is evidence to substantiate the claim that the selection effect is a relevant and important variable in modeling the impact of dirty production and of trade on environmental quality. Two, the findings provide evidence of the robustness of the earlier results with respect to estimates of the environmental effects of scale, selection, technique, and composition.

Finally, in Model E, the trade variable foreign direct investment (FDI) is added to the main Model B to examine the environmental impact of the flow of factor movement across borders. Results show that for the pollutants sulfur oxides and nitrogen oxides, adding the FDI variable worsens the R^2-statistic when compared to the main Model B. For sulfur oxides, overall R^2 is 0.2722 and 0.2610 for Models B and E, respectively, while for nitrogen oxides, overall R^2 is 0.7685 and 0.7535, respectively. In the case of volatile organic compounds, the R^2-statistic in Model B is 0.6500, and it is slightly improved in Model E at 0.6514.

Coefficient estimates of the effect of the FDI variable are statistically significant at the 1 percent level for sulfur oxides and at the 10 percent level for nitrogen oxides, but are not statistically significant at the conventional levels for volatile organic compounds. A 1 unit increase in FDI/ km^2 leads to a 0.9 percent decrease in sulfur oxides emissions and a 0.1 percent decrease in nitrogen oxides. Therefore, in the model for sulfur oxides, there is strong evidence to suggest that inward flow of foreign direct investment mitigate the emissions level of sulfur oxides, and some evidence to suggest that foreign direct investment lowers the emissions of nitrogen oxides.

Note that the estimates of the coefficients of selection effect variable, Companies/ km^2, are statistically significant for all three pollutants, sulfur oxides, nitrogen oxides and volatile organic compounds at the 10, 5 and 1 percent levels of significance, respectively. These results indicate the robustness of earlier findings with respect to coefficient estimates for the selection effect variable.

Estimates of the scale, technique, composition, trade and population density are statistically significant at 5 percent level or less for sulfur oxides (SOx). In the case of interaction variables between trade-intensity and the selection and technique effects, coefficient estimates are found to be statistically significant at the 5 percent level or less.

In the model for nitrogen oxides (NOx), coefficient estimates of the composition effect variable and the relative-income variable are significant at the conventional levels.

Finally, for volatile organic compounds (VOC), estimates of the scale, trade intensity and trade-induced composition effects are significant at the conventional levels of significance.

Therefore, the results show that in Model E, the signs and magnitudes of statistically significant coefficient estimates for the three pollutants: sulfur oxides, nitrogen oxides and volatile organic compounds, conform to and are consistently nearly identical to the signs and magnitudes of significant estimates in the main Model B. The exceptions are the mixed responses to the environmental effects of scale, technique and composition in Model E for nitrogen oxides and volatile organic compounds.

Comparatively, the coefficient estimates of the effects of selection and relative-income variables for nitrogen oxides emissions (NOx) are, respectively, 0.257 and -0.006 in Model B, and 0.246 and -0.005 in Model E. Meanwhile, the coefficient estimates of the statistically significant effects of the selection, scale, trade intensity and trade-induced composition effects on volatile organic compounds (VOC) are, respectively, 0.517, 0.112, -0.004 and -0.002 in Model B, and 0.524, 0.112, -0.003 and -0.002 in Model E. Thus, the results suggest that adding the foreign direct investment variable in Model E in the case of volatile organic compounds does nothing to improve or worsen the estimations of variable effects.

Furthermore, since evidence fails to reject the null hypotheses that the coefficient estimate of the foreign direct investment (FDI) effect is zero, dropping the FDI as a variable will not affect the model specification for volatile organic compounds.

4.8 Discussion

The impact of intra-industry trade on environmental quality can be decomposed into scale, selection and technique effects. Previous empirical studies based on the traditional trade framework shows that the environmental effects of inter-industry trade can be decomposed into scale, composition and technique effects. Most, if not all countries engage in both intra- and inter-industry trade. The premise of the analysis in this paper is that international trade is composed of both types of trade, namely, trade in homogenous goods described by the theoretical framework of traditional trade, and trade in differentiated goods described by the framework of new trade theory. The integrated environmental effects of both inter- and intra-industry trade can therefore be decomposed into four environmental effects namely the scale, technique, selection and composition effects.

The selection effect distinguishes the impact of trade driven by market structure and increasing returns from the impact of trade that is driven by comparative advantage based on cross-country differences in factor abundance. If countries engage in the pollution-intensive production of homogenous and differentiated goods in an integrated economy, then an empirical estimation of the total impact of trade on the environment needs to account for a selection effect in addition to scale, technique and composition effects. In this paper, findings show there is strong evidence of the statistical significance of the selection effect in the trade-environment linkage.

Results show that the ex-ante prediction of an increasing relationship between the selection effect and emissions level is borne out in the data. Statistically significant coefficient estimates are found have positive signs, a result that is robust across the six empirical models and across all three pollutants, sulfur oxides, nitrogen oxides and volatile organic compounds. These results conform to the prediction of a nonnegative trade-induced selection effect postulated by the intra-industry trade framework under the assumption of both non-CES and non-homothetic utility function. In other words, there is strong evidence to support the hypothesis that the level of emissions is increasing in the selection effect. A theoretical explanation is that, trade in differentiated goods induces a negative selection effect: openness to trade implies increased competition from abroad which leads to a reduction in the number of domestic firms or in the number of product varieties. Then, holding the scale and technique effects constant, a decrease in the number of firms leads to a decrease in emissions level.

Furthermore, the current analysis suggests there is a linear and positive relationship between selection and emissions level. This finding provides evidence for the intra-industry trade framework which assumes that firms have identical technology where a fall in the number of firms implies a proportionate fall in emissions level, holding other factors constant.

Estimates of responses to the second environmental effect, the scale effect, are as follows. First, in the main model of the current analysis, Model B, statistically significant estimates of a positive relationship between the scale of production and emissions level are consistent with theoretical predictions. In the models for sulfur oxides and volatile organic compounds, coefficient estimates suggests that an increase (decrease) the level of scale of production raises (lowers) the emissions levels of sulfur oxides and volatile organic compounds, holding other factors equal. Second, findings show that responses to the scale effect variable are statistically significant for the functional form that specifies linearity in the scale variable. This result provides evidence to indicate that for countries in the sample, the assumption of homothetic production or consumption prevails over the assumption of non-homothetic functions. In the context of international trade effects, since homotheticity is a feature consistent with trade in intra- rather than inter-industry goods, the evidence suggests that the realization of data is more consistent with trade driven by market structure and increasing returns rather than by cross-country differentials in factor endowments.

For the third environmental effect, the technique effect, coefficient estimates are negatively signed and statistically significant for sulfur oxides estimations. However, estimates are not significant at the conventional levels for nitrogen oxides and volatile organic compounds. This finding suggests that for sulfur oxides, there is evidence to support the hypothesis that emissions level decreases in abatement activities or in the stringency of environmental regulations. On the other hand, in the cases of nitrogen and volatile organic compounds, one reason for the lack of evidence for the technique effect is that nitrogen oxides and volatile organic compounds are not subjected to strict environmental enforcement. The pollutants are difficult to regulate: nitrogen oxides gases are formed from the emissions generated in transportation vehicles, and they contribute to ozone formations and fine particle pollution. Volatile organic compounds emissions are mainly sourced from transportation and indoor products. In contrast, sulfur oxides emissions are subjected to rigorous environmental laws and standards at plant and firm sites, and in the abating process which includes regulation on equipment requirements and production methods.

Findings also suggest that similar to the scale effect, the technique effect is statistically significant when measured as level-form income per capita but not statistically significant when measured in non-linear or quadratic form. This result provides evidence to suggest that the assumption of a homothetic consumption function is relevant for countries in the sample. The assumption is consistent with a CES utility function in a pollution model of intra-industry trade.

For the fourth environmental effect, the composition effect, the analysis finds evidence to support the theoretical prediction of a positive and increasing relationship between emissions level and capital intensity. Similar to the technique effect, the composition effect variable is statistically significant in the models for sulfur oxides, but is not significant in the models for nitrogen oxides and volatile organic compounds. One possible explanation for these findings is that sulfur oxides are generated in highly capital intensive production processes but that nitrogen oxides and volatile organic compounds emission methods are not dependent on capital-intensive production sectors.

In the open trade context, statistically significant coefficient estimates of the interacted terms between capital intensity and trade intensity (K/L x TI) provide strong evidence to suggest that trade-induced composition effects lead to increased sulfur oxides emissions.

Interestingly, in contrast to the scale and technique effects, coefficient estimates of the composition effect variables are statistically significant in the quadratic or non-linear form, but are not statistically significant in the level-form. This result conforms to the theoretical assumption of inter-industry trade, where the impact of capital accumulation on pollution is linked to non-homothetic production or consumption, owing to cross-country differentials in income and/or production techniques.

Finally, in the case of the environmental effect of openness to trade or trade liberalization, coefficient estimates are statistically significant in the models for sulfur oxides and volatile organic compounds models. For sulfur oxides, coefficient estimates of the trade intensity variable are consistently significant and negative in signs for the five models considered, Models A through E. For volatile organic compounds, in four out of the five model specifications, estimations yield statistically significant trade intensity coefficient estimates. These results suggest strong evidence for the prediction that greater openness to trade or greater trade liberalization leads to lower emissions level. One explanation for the findings is that when pollutants are confined to domestic borders, imports of cleaner goods produced abroad substitute for dirty goods produced domestically, thus mitigating emissions level in the home market. A second explanation is that openness to trade brings in cleaner and more efficient abatement technology that is imbedded in imported goods or imported production technology. The diffusion of cleaner techniques of production in the domestic market alleviates emissions production. Interestingly, this possibility is consistent with the result of negative coefficient estimates on foreign direct investment, which are statistically significant in the models for sulfur oxides.

I note that the parsimonious model specifications adopted in the current analysis captures the essential aspects of the trade-environment relationship as postulated by theory. Statistically significant semi-elasticity estimates of variables do not differ in any great manner across the fixed effects and random effects estimations. In the fixed effects Models A and B, coefficient estimates are invariably found to be identical or nearly identical in their magnitudes. The signs or direction of effects of statistically significant variables are consistently identical across models and across estimators. Furthermore, and more importantly, statistically significant results conform to theoretical predictions and can be explained in terms of the underlying assumptions of the frameworks which form the basis of the econometric models specified. Findings are supportive of theoretical expectations consistent with intra-industry trade theory – this is not surprising considering our data describes countries that are known to engage in the trade of differentiated goods. But the findings also support theoretical predictions of inter-industry trade as evidenced in the estimates of the composition effect. Statistically significant capital intensity coefficients conform to the assumption that the trade-induced composition effect is generated by non-linearity in the techniques of production, brought about by income and price differentials across countries. On the other hand, the composition effect estimates do not conform to assumptions that can be explained by intra-industry trade and homothetic production. This result is significant and interesting since new trade theory does not generate a composition effect.

4.9 Conclusion

International trade is comprised of trade in both homogenous and differentiated goods. Theory suggests the environmental effects of an integrated open economy can be explained by factors that drive inter-industry as well as intra-industry trade. In this paper, an analysis of panel data from OECD countries provides evidence of the following results. First, strong empirical evidence supports the hypotheses postulated by theory that emission levels are increasing in the scale of production, in emission intensity, in the number of firms, and in the composition of the economy. Second, the estimation of the impact of international trade on environmental quality needs to control for the selection effect, in addition to the widely recognized scale, technique and composition effects. Statistically significant estimates of the selection effect are shown to be robust across six different model specifications and across three types of pollutant. Third, in consonant with the study by Antweiler et al. (2001), the findings in this paper show that responses to the scale, technique and composition effects are statistically significant for sulfur oxides. However, in contrast to findings in Antweiler et al. (2001), the results show that for the countries in the sample, estimates of the scale and technique effects can be explained by the assumptions of homothetic production or consumption, consistent with the intra-industry or new trade framework rather than with inter-industry or traditional trade framework. On the other hand, the estimates of the composition effect can be described by the assumption of non-homothetic production, consistent with the inter-industry trade framework. This result replicates the finding in Antweiler et al. (2001). Estimations of the scale, technique and composition effects for the pollutants nitrogen oxides and volatile organic compounds generate mixed findings, which can be explained by the inherent characteristics, processes and sources of the respective pollutants. Fourth, the analysis suggests that openness to trade or trade liberalization is beneficial to the environment in that there is strong evidence to indicate that greater openness to trade or increased liberalization of trade frictions leads to lower levels of emissions.

The findings in this paper build on previous findings in literature which seek to resolve the heated debate of whether international trade is good or bad for the environment. This paper departs from previous work by showing that the estimation of the environmental impact of international trade needs to account for a selection effect, a variable that helps explain the total volume and integrated patterns of the exchange of goods across borders. The omission of a relevant variable can lead to specification error and biased estimates. The significance of unbiased estimation lies in the effect it has on resolving an important issue which may have implications on policy recommendations.

Finally, further empirical investigations based on the model presented in this paper may include testing the theoretical predictions on a larger sample to include a greater number of countries in the world economy, and on groups of countries defined by developmental stages such as the developing countries including China and India, and by geographical proximities such as the North and South countries.

APPENDICES

Appendix A: Monopolistic Competition, Trade and the Environment

A.1: Production

The profit function is the firm's revenue less labor cost and pollution taxes such that:

(A.1) $$\pi_i = p(1-\theta)q_i - w\alpha - w\beta q_i - \tau z_i$$

where

$$p = p_i\left(\left(1-\theta_i\right)q_i\right)$$

By the substitution of equations (1.3) and (1.7) into (A.1), the following profit function is obtained:

(A.2) $$\pi_i = p_i\left(\left(1-\theta_i\right)q_i\right)(1-\theta_i)q_i - W\alpha - W\beta q_i - \tau(1-\theta_i)^{\delta} q_i$$

First Order Conditions

The first order conditions for profit maximization with respect to q implies:

(A.3) $$p'\left(1-\theta\right)^2 q + p\left(1-\theta\right) - w\beta - \tau(1-\theta)^{\delta} = 0$$

Divide equation (A.3) through by $\left(1-\theta\right)$ and rearrange to obtain:

(A.4) $$p'\left(1-\theta\right)q + p - \tau(1-\theta)^{\delta-1} = w\beta\left(1-\theta\right)^{-1}$$

The first order conditions for profit maximization with respect to θ is:

(A.5) $$-qp'\left(1-\theta\right)q - qp + \delta\tau\left(1-\theta\right)^{\delta-1} q = 0$$

Divide (A.5) by q and rearranging, equation (A.5) can be rewritten as:

(A.6) $$p'\left(1-\theta\right)q + p - \delta\tau(1-\theta)^{\delta-1} = 0$$

Second Order Conditions

The second order condition for profit maximization with respect to quantity of output is:

(A.7) $$\frac{\partial^2 \pi}{\partial q^2} = p''(1-\theta)q \cdot (1-\theta)q + p'(1-\theta)^2 + p'(1-\theta)$$

Since $p' = \frac{\partial p}{\partial q} < 0$ and assuming $p'' = \frac{\partial^2 p}{\partial q^2} < 0$, then $\frac{\partial^2 \pi}{\partial q^2} < 0$ and satisfy the second order condition for a maximum.

The second order condition for profit maximization with respect to quantity of abatement is:

$$\frac{\partial^2 \pi}{\partial \theta^2} = -qp''(-q) \cdot (1-\theta)q + qp'(1-\theta)q \cdot (-1)q + p'(-q) + (\delta - 1)\delta\tau(1-\theta)^{\delta-2} \cdot (-1)$$

or

(A.8) $$\frac{\partial^2 \pi}{\partial \theta^2} = p''(1-\theta)q^3 - p'(1-\theta)q^3 - p'q - (\delta-1)\delta\tau(1-\theta)^{\delta-2}$$

Since $p' = \frac{\partial p}{\partial \theta} > 0$ and assuming $p'' = \frac{\partial^2 p}{\partial \theta^2} < 0$, then $\frac{\partial^2 \pi}{\partial \theta^2} < 0$ and satisfy the second order condition for a maximum.

Solve for the abatement fraction, emission per unit output, the pricing equation, and the number of firms/product varieties

Equate equations (A.4) and (A.6) to obtain:

$$\delta\tau(1-\theta)^{\delta-1} - \tau(1-\theta)^{\delta-1} = w\beta(1-\theta)^{-1}$$

Divide through by $(1-\theta)^{-1}$, collect terms and rearrange to obtain:

$$\tau(1-\theta)^{\delta}(\delta-1) = w\beta$$

Solve for theta:

(A.9) $$\theta = 1 - \left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}$$

Thus, the fraction of output allocated towards abatement, θ, is fixed and is decreasing in wage w, and the labor coefficient β; it is increasing in the emission tax τ, and the elasticity of emission with respect to the consumption fraction of output δ.

Then, substituting into the equation for emission per unit (1.9), emission intensity can be written as:

$$e = (1-\theta)^{\delta}$$

(A.10) $$e = \left(1 - \left(1 - \frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}\right)^{\delta} \Rightarrow e = \left(\frac{w\beta}{\tau(\delta-1)}\right)$$

Marginal revenue in elasticity term

Let $C = Lc = (1-\theta)q$

Then,

$$p = p(C) = p((1-\theta)q)$$

Taking the derivative of price with respect to quantity of output:

$$\frac{\partial p}{\partial q} = \frac{\partial p}{\partial C} \cdot \frac{\partial C}{\partial q} = \frac{\partial p}{\partial C} \cdot (1-\theta) = p'(1-\theta)$$

Then, from equation (1.11), the first order condition of profit maximization with respect to output:

$$p'(1-\theta)^2 q + p(1-\theta) - w\beta - \tau(1-\theta)^{\delta} = 0$$

Rewrite as:

$$\frac{\partial p}{\partial C}(1-\theta)q \cdot (1-\theta) + p(1-\theta) = w\beta + \tau(1-\theta)^{\delta}$$

Substituting for demand, $C = (1-\theta)q$,

$$\frac{\partial p}{\partial C}C(1-\theta)+p(1-\theta)=w\beta+\tau(1-\theta)^{\delta}$$

Divide through by $(1-\theta)$:

$$\frac{\partial p}{\partial C}C+p=\frac{w\beta}{(1-\theta)}+\tau(1-\theta)^{\delta-1}$$

Multiply the first term on the LHS by p/p to obtain:

$$p\frac{\partial p}{\partial C}\frac{C}{p}+p=\frac{w\beta}{(1-\theta)}+\tau(1-\theta)^{\delta-1}$$

$$p\left(1-\frac{1}{\eta}\right)=\frac{w\beta}{(1-\theta)}+\tau(1-\theta)^{\delta-1}$$

where $\eta=-\left(\frac{\partial C}{C}\right)\Big/\left(\frac{\partial p}{p}\right)$ is the elasticity of demand.

Substituting for the price elasticity of demand, we can rewrite equation (A.4) as:

$$\text{(A.11)}\quad p\left(1-\frac{1}{\eta}\right)=\frac{w\beta}{(1-\theta)}+\tau(1-\theta)^{\delta-1}$$

where η is the price elasticity of demand.

Then by substitution of equation (A.9) into equation (A.11), the pricing equation can be obtained as follows:

$$p\left(1-\frac{1}{\eta}\right)=\frac{w\beta}{\left(1-\left(1-\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}\right)\right)}+\tau\left(1-\left(1-\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}\right)\right)^{\delta-1}$$

Simplifying, write the equation as:

$$p\left(1-\frac{1}{\eta}\right)=\left(w\beta\left(\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}\right)^{-1}+\tau\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{\delta-1}{\delta}}\right)$$

Divide the LHS and the RHS by wage rate, then rearrange and collect terms to obtain:

(A.12) $$\frac{p}{w}\left(1-\frac{1}{\eta}\right)=\beta\left(\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}\right)^{-1}+\frac{\tau}{w}\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{\delta-1}{\delta}}$$

Equation (A.12) is the pricing rule.

Rearrange to obtain:

$$p\left(1-\frac{1}{\eta}\right)=(w\beta)^{\frac{\delta-1}{\delta}}\left[(\tau(\delta-1))^{\frac{1}{\delta}}\left(\frac{\delta}{(\delta-1)}\right)\right]=(w\beta)\left(\frac{w\beta}{\tau(\delta-1)}\right)^{-\frac{1}{\delta}}\left(\frac{\delta}{(\delta-1)}\right)$$

$$p\left(1-\frac{1}{\eta}\right)=(w\beta)e^{-\frac{1}{\delta}}\left(\frac{\delta}{(\delta-1)}\right)$$

That is,

(A.12') $$\frac{p}{w}=\left(1-\frac{1}{\eta}\right)^{-1}e^{-\frac{1}{\delta}}\beta\left(\frac{\delta}{(\delta-1)}\right)$$

Equation (A.12') is the PE line.

From the Zero-profit condition, obtain $P = AC$ in the following way:

$$p(1-\theta)q = w\alpha + w\beta q + \tau(1-\theta)^{\delta} q$$

Divide by quantity of output:

$$p(1-\theta) = w\alpha q^{-1} + w\beta + \tau(1-\theta)^{\delta}$$

Divide through by wage rate, rearrange and collect terms to obtain:

$$\frac{p}{w} = \left((1-\theta)\right)^{-1}\left[\alpha q^{-1} + \beta + \frac{\tau}{w}(1-\theta)^{\delta}\right]$$

Substituting for θ, rewrite the above as:

$$\frac{p}{w} = \left(\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}\right)^{-1}\left[\frac{\alpha}{q} + \beta + \frac{\tau}{w}\left(\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}\right)^{\delta}\right]$$

or

$$\frac{p}{w} = \left(\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}\right)^{-1}\left[\frac{\alpha}{q} + \beta\left(1 + \frac{1}{(\delta-1)}\right)\right]$$

Simplifying, obtain:

(A.13) $$\frac{p}{w} = \left(\frac{w\beta}{\tau(\delta-1)}\right)^{-\frac{1}{\delta}}\left[\alpha q^{-1} + \beta\left(\frac{\delta}{(\delta-1)}\right)\right]$$

Equation (A.13) is the ZE or zero-profit line.

To solve for the number of firms, use the Full-employment condition:

$$L = \sum_{i=1}^{n}(\alpha + \beta q_i) = n(\alpha + \beta q) = n\left(\alpha + \beta Lc \big/ (1-\theta)\right) = n\left(\alpha + \frac{\beta Lc}{\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}}\right)$$

Solve for the number of firms, n:

(A.14) $$n = L\left(\alpha + \frac{\beta Lc_i}{\left(\frac{w\beta}{\tau(\delta-1)}\right)_i^{\frac{1}{\delta}}}\right)^{-1} = \frac{1}{\alpha L^{-1} + \beta c\left(\frac{w\beta}{\tau(\delta-1)}\right)^{-\frac{1}{\delta}}}$$

Growth in Emission level and the Scale, Technique and Selection Effect:

From equation (1.25):

(1.25) $$\sum_{i=1}^{n} z_i = \sum_{i}^{n} e_i q_i \Rightarrow nz = n \cdot e \cdot q$$

Let $Z = nz$ and rewrite (1.25) as:

(A.15) $$Z = neq$$

Take a logarithmic transformation of equation (A.15) and write as:

(A.15') $$\log Z = \log n + \log e + \log q$$

Totally differentiate:

(A.15") $$\frac{1}{Z}dZ = \frac{1}{n}dn + \frac{1}{e}de + \frac{1}{q}dq \quad or \quad \frac{dZ}{Z} = \frac{dn}{n} + \frac{de}{e} + \frac{dq}{q}$$

Then, take the percent change (multiply through by 100%) to obtain:

(A.16) $$\hat{Z} = \hat{n} + \hat{e} + \hat{q}$$

Equation (A.16) shows that the change or growth in total emission can be decomposed into, or is the sum of, the selection, technique and scale effects (respectively).

A.2 PE AND ZE LINES

Use the FOC with respect to q from the profit maximization problem and the Zero-profit condition to obtain the PE and ZE curves.

The equilibrium conditions can be written as:

(A.12') $$\frac{p}{w} = \left(1 - \frac{1}{\eta}\right)^{-1} \left(\frac{w\beta}{\tau(\delta - 1)}\right)^{-\frac{1}{\delta}} \beta \left(\frac{\delta}{(\delta - 1)}\right)$$

(A.13) $$\frac{p}{w} = \left(\frac{w\beta}{\tau(\delta - 1)}\right)^{-\frac{1}{\delta}} \left[\alpha q^{-1} + \beta \left(\frac{\delta}{(\delta - 1)}\right)\right]$$

Rewrite as:

$$PE: \quad \frac{p}{w} = \left(1 - \frac{1}{\eta(c)}\right)^{-1} \tau^{\frac{1}{\delta}} \left(\frac{(w\beta)}{(\delta-1)}\right)^{-\frac{1}{\delta}} \beta\left(\frac{\delta}{(\delta-1)}\right)$$

$$where \quad \eta = \eta(c(q))$$

$$ZE: \quad \frac{p}{w} = \tau^{\frac{1}{\delta}} \left(\frac{(w\beta)}{(\delta-1)}\right)^{-\frac{1}{\delta}} \left[\alpha q^{-1} + \beta\left(\frac{\delta}{(\delta-1)}\right)\right]$$

Let $\mathrm{M} = \left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}$ and $\mathrm{B} = \beta\left(\frac{\delta}{(\delta-1)}\right)$

Then, rewrite the PE line as:

(A.12")
$$\frac{p}{w} = \left(1 - \frac{1}{\eta(c(q))}\right)^{-1} \mathrm{M}^{-1}\mathrm{B}$$

Rewrite the ZE line as:

(A.13')
$$\frac{p}{w} = \mathrm{M}^{-1}\left[\alpha q^{-1} + \mathrm{B}\right]$$

Slopes of the PE and ZE curves

To find the slopes of the PE and ZE curves, totally differentiate the two equations with respect to output level. Assume no changes in the parameters, wage rate and emission tax rate.

Total differentiation of the PE equation implies:

$$\frac{d\left(\frac{p}{w}\right)}{dq} = \left\{-\left(1-(\eta(c))^{-1}\right)^{-2} (\eta(c))^{-2} \frac{\partial \eta}{\partial c} \cdot \frac{\partial c}{\partial q}\right\}$$

The PE curve is upward sloping since $\frac{\partial \eta}{\partial c} < 0$ and $\frac{\partial c}{\partial q} > 0$.

Total differentiation of the ZE equation implies:

$$d\left(\frac{p}{w}\right)=\left\{\mathrm{M}^{-1}(-1)\alpha q^{-2}\right\}dq$$

Thus,

$$\frac{d\left(\frac{p}{w}\right)}{dq}=-\mathrm{M}^{-1}\alpha q^{-2}<0$$

Therefore, ZE curve is downward sloping.

Shifts in PE and ZE due to a change in emission tax rate:

Assume no changes in output level, wage rate and the parameters.

Let $\varpi=\left(\frac{w\beta}{(\delta-1)}\right)^{\frac{1}{\delta}}$, $\mathrm{B}=\beta\left(\frac{\delta}{(\delta-1)}\right)$ and rewrite the PE and ZE curves as the following:

$$PE:\quad \frac{p}{w}=\left(1-(\eta)^{-1}\right)^{-1}\tau^{\frac{1}{\delta}}\varpi^{-1}\mathrm{B}$$

$$ZE:\quad \frac{p}{w}=\tau^{\frac{1}{\delta}}\varpi^{-1}\left[\alpha q^{-1}+\mathrm{B}\right]$$

Totally differentiate the PE curve with respect to emission tax rate:

$$d\left(\frac{p}{w}\right)-\left\{\frac{1}{\delta}\tau^{\frac{1}{\delta}-1}\cdot\left(\left(1-\frac{1}{\eta}\right)^{-1}\varpi^{-1}\mathrm{B}\right)\right\}d\tau=0$$

Therefore,

$$\frac{d(PE)}{d\tau}=\frac{d\left(\frac{p}{w}\right)}{d\tau}=\left\{\frac{1}{\delta}\tau^{\frac{1}{\delta}-1}\left(\left(1-\frac{1}{\eta}\right)^{-1}\varpi^{-1}\mathrm{B}\right)\right\}>0 \qquad QED$$

Therefore, a change in emissions tax shifts the PE curve in a positive direction.

Totally differentiate the ZE curve:

$$d\left(\frac{p}{w}\right)-\left\{\frac{1}{\delta}\tau^{\frac{1}{\delta}-1}\varpi^{-1}\left[\alpha q^{-1}+\mathrm{B}\right]\right\}d\tau=0$$

Thus,

$$\frac{d(ZE)}{d\tau}=\frac{d\left(\frac{p}{w}\right)}{d\tau}=\frac{1}{\delta}\tau^{\frac{1}{\delta}-1}\varpi^{-1}\left[\alpha q^{-1}+\mathrm{B}\right]>0 \qquad QED$$

Therefore, a change in emissions tax shifts the ZE in a positive direction.

A.3 Comparative Statics of the Effect of Change in Emission Tax on Abatement Level, Price Level, Emission Intensity, Output Level and the Number of Product Varieties (Comparative Statics of Change in Emissions Tax on PE and ZE Curves)

Assume no changes in the parameters and the wage rate.

(i) From the first order condition of profit maximization with respect to output, q, and by substitution for the fraction of output allocated towards abatement in equation (A.7), and simplifying, the PE curve is:

(A1.12')[20]
$$\frac{p}{w}=\left(1-\frac{1}{\eta}\right)^{-1}\tau^{\frac{1}{\delta}}\left(\frac{(w\beta)}{(\delta-1)}\right)^{-\frac{1}{\delta}}\beta\left(\frac{\delta}{(\delta-1)}\right)$$

where η is the elasticity of demand such that $\eta=\eta\left(c(q,\tau)\right)$

Let $\varpi=\left(\frac{w\beta}{(\delta-1)}\right)^{\frac{1}{\delta}}$ *and* $\mathrm{B}=\beta\left(\frac{\delta}{(\delta-1)}\right)$

Then rewrite equation (A1.12') as the following:

(A1.12")
$$\frac{p}{w}=\left(1-\frac{1}{\eta}\right)^{-1}\tau^{\frac{1}{\delta}}\varpi^{-1}\mathrm{B}$$

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[20] Note that the first order condition of profit maximization with respect to the fraction of output allocated towards abatement, θ, which is equation (1.13) yields the same equation as (A1.12) after substitution of the equilibrium value of θ.

From the zero profit condition and after substituting for the fraction of output allocated towards abatement in equation (A.7) and simplifying, we rewrite equation (1.17) as:

$$\text{(A1.13)} \qquad \frac{p}{w} = \tau^{\frac{1}{\delta}} \left(\frac{(w\beta)}{(\delta-1)} \right)^{-\frac{1}{\delta}} \left[\alpha q^{-1} + \beta \left(\frac{\delta}{(\delta-1)} \right) \right]$$

$$\text{Let } \varpi = \left(\frac{w\beta}{(\delta-1)} \right)^{\frac{1}{\delta}} \; \textit{and } \mathrm{B} = \beta \left(\frac{\delta}{(\delta-1)} \right)$$

Then (A1.13) can be written as:

$$\text{(A1.13')} \qquad \frac{p}{w} = \tau^{\frac{1}{\delta}} \varpi^{-1} \left[\alpha q^{-1} + \mathrm{B} \right]$$

In the following, we evaluate the effects of an increase in the emissions tax, τ, on total production, q, real price of consumption, $\frac{p}{w}$, consumption, c, and other endogenous variables.

The equilibrium system of equations can be simplified by substitutions (see dissertation equations 2.18 and 2.19) to two equations that are functions are production, price, and the emissions tax,

$$\text{(A1.14)} \qquad F^1 = \left(1-\eta^{-1}\right)^{-1} \tau^{\frac{1}{\delta}} \varpi^{-1} B - \frac{p}{w} \equiv 0$$

$$\text{(A1.15)} \qquad F^2 = \tau^{\frac{1}{\delta}} \varpi^{-1} \left[\alpha q^{-1} + B \right] - \frac{p}{w} \equiv 0$$

where w is a constant.

The negative of elasticity of demand, η, is a function of consumption, c, as described by equations 2.3 in the dissertation,

$$\text{(A1.16)} \qquad \eta = \eta(c)$$

with $\frac{\partial \eta}{\partial c} < 0$ as indicated by dissertation equation 2.4.

Equations 2.8 and 2.14 show that c is, in turn, a function of q and τ. Using equation (2.24), consumption is written as:

$$\text{(A1.17)} \qquad c = c(q,\tau) = L^{-1} \varpi \tau^{-\frac{1}{\delta}} q$$

with derivatives

(A1.18) $$\frac{\partial c}{\partial q} = L^{-1}\varpi\tau^{-\frac{1}{\delta}}$$

and

(A1.19) $$\begin{aligned}\frac{\partial c}{\partial \tau} &= -\delta^{-1}\tau^{-1}L^{-1}\varpi\tau^{-\frac{1}{\delta}}q \\ &= -\delta^{-1}\tau^{-1}q\frac{\partial c}{\partial q}\end{aligned}$$

Equations (A1.14) may be written as

(A1.20) $$F^1 = \left\{1-\eta^{-1}\left[c(q,\tau),p\right]\right\}^{-1}\tau^{\frac{1}{\delta}}\varpi^{-1}B - \frac{p}{w} \equiv 0$$

Derive the partial derivatives of F^1 and F^2 with respect to the production, price, and the environmental tax. The partial derivatives of F^1 are

(A1.21) $$F_q^1 = -\left(1-\eta^{-1}\right)^{-2}\eta^{-2}\frac{\partial \eta}{\partial c}\frac{\partial c}{\partial q}\tau^{\frac{1}{\delta}}\varpi^{-1}B > 0$$

(A1.22) $$F_p^1 = -w^{-1} < 0$$

(A1.23) $$\begin{aligned}F_\tau^1 &= -\left(1-\eta^{-1}\right)^{-2}\eta^{-2}\frac{\partial \eta}{\partial c}\frac{\partial c}{\partial \tau}\tau^{\frac{1}{\delta}}\varpi^{-1}B + \delta^{-1}\tau^{-1}\tau^{\frac{1}{\delta}}\varpi^{-1}B\left(1-\eta^{-1}\right)^{-1} \\ &= \left(1-\eta^{-1}\right)^{-2}\tau^{\frac{1}{\delta}}\varpi^{-1}B\left[-\eta^{-2}\frac{\partial \eta}{\partial c}\frac{\partial c}{\partial \tau} + \left(1-\eta^{-1}\right)\delta^{-1}\tau^{-1}\right] \gtreqless 0\end{aligned}$$

The partial derivatives of F^2 are:

(A1.24) $$F_q^2 = -\tau^{\frac{1}{\delta}}\varpi^{-1}\alpha q^{-2} < 0$$

(A1.25) $$F_p^2 = -w^{-1} < 0$$

(A1.26) $$F_\tau^2 = \delta^{-1}\tau^{-1}\tau^{\frac{1}{\delta}}\varpi^{-1}\left[\alpha q^{-1} + B\right] = \delta^{-1}\tau^{-1}\tau^{\frac{1}{\delta}}\varpi^{-1}B\left(1-\eta^{-1}\right)^{-1} > 0$$

where the second line of equation (A1.26) comes from using equations (A1.14) and (A1.15) to solve for $\left(1-\eta^{-1}\right)^{-1}B = \alpha q^{-1} + B$.

F^1 is the PE curve and describes the equilibrium in the consumption market. The slope of the PE curve is $\dfrac{d\frac{p}{w}}{dq} = -\dfrac{F_q^1}{F_p^1} w > 0$. F^2 is the ZE curve and describes the zero profit equilibrium in production. The slope of the ZE curve is $\dfrac{d\frac{p}{w}}{dq} = -\dfrac{F_q^2}{F_p^2} w < 0$.

Equations (A1.14) and (A1.15) give a non-linear two equation system that determines the equilibrium values of production and the price of consumption. Derive the system of differential equations from equations (A1.14) and (A1.15):

(A1.27)
$$F_q^1 dq + F_p^1 dp + F_\tau^1 d\tau = 0$$
$$F_q^2 dq + F_p^2 dp + F_\tau^2 d\tau = 0$$

Take the total derivatives $\dfrac{dq}{d\tau}$ and $\dfrac{dp}{d\tau}$ based on (A1.27) by dividing each equation by $d\tau$. In matrix form, the result of dividing by the differential of the emission tax is

(A1.28)
$$A\begin{bmatrix} \dfrac{dq}{d\tau} \\ \dfrac{dp}{d\tau} \end{bmatrix} = \begin{bmatrix} -F_\tau^1 \\ -F_\tau^2 \end{bmatrix}$$

where

(A1.29)
$$A = \begin{bmatrix} F_q^1 & F_p^1 \\ F_q^2 & F_p^2 \end{bmatrix}$$

Solve the system for the total derivatives by finding the inverse of A,

(A1.30)
$$A^{-1} = \begin{bmatrix} F_q^1 & F_p^1 \\ F_q^2 & F_p^2 \end{bmatrix} D^{-1}$$

where

(A1.30)
$$D = F_q^1 F_p^2 - F_q^2 F_p^1 < 0$$

The sign of D^{-1} follows from equations (A1.21), (A1.22), (A1.24), and (A1.25).

Multiplying both sides of equation (A1.30) by A^{-1} gives

(A1.31) $$\begin{bmatrix} \dfrac{dq}{d\tau} \\ \dfrac{dp}{d\tau} \end{bmatrix} = \begin{bmatrix} F_p^2 & -F_p^1 \\ -F_q^2 & F_q^1 \end{bmatrix} \begin{bmatrix} -F_\tau^1 \\ -F_\tau^2 \end{bmatrix} D^{-1}$$

Performing the matrix multiplication gives

(A1.32) $$\frac{dq}{d\tau} = D^{-1}\left(F_p^1 F_\tau^2 - F_p^2 F_\tau^1\right)$$

and

(A1.33) $$\frac{dp}{d\tau} = D^{-1}\left(F_q^2 F_\tau^1 - F_q^1 F_\tau^2\right)$$

Substituting equations (A1.21), (A1.23), (A1.25), and (A1.26) into equation (A1.32) gives

(A1.34)

$$\frac{dq}{d\tau} = -D^{-1}w^{-1}\delta^{-1}\tau^{-1}\tau^{\frac{1}{\delta}}\varpi^{-1}B\left(1-\eta^{-1}\right)^{-1} - D^{-1}w^{-1}\left(1-\eta^{-1}\right)^{-2}\eta^{-2}\frac{\partial\eta}{\partial c}\frac{\partial c}{\partial\tau}\tau^{\frac{1}{\delta}}\varpi^{-1}B$$
$$+D^{-1}w^{-1}\delta^{-1}\tau^{-1}\tau^{\frac{1}{\delta}}\varpi^{-1}B\left(1-\eta^{-1}\right)^{-1}$$

The first term in the second line of equation (A1.33) cancels with the fourth line, so

(A1.35) $$\frac{dq}{d\tau} = -D^{-1}w^{-1}\left(1-\eta^{-1}\right)^{-2}\eta^{-2}\frac{\partial\eta}{\partial c}\frac{\partial c}{\partial\tau}\tau^{\frac{1}{\delta}}\varpi^{-1}B$$

Thus, since $\frac{\partial\eta}{\partial c} < 0,\ \ c > 0\ \ \textit{and}\ \ \eta > 0$, these imply $\frac{\partial\eta}{\partial c}\frac{c}{\eta} < 0$, so that $\frac{dq}{d\tau} < 0$.

Analysis of equation (A1.33) shows that consumption price rises in response to an increase in the emission tax,

(A1.36) $$\frac{dp}{d\tau} = D^{-1}\tau^{\frac{2}{\delta}}\varpi^{-2}B\delta^{-1}\tau^{-1}q^{-1}\left[B\eta^{-1}\frac{\partial\eta}{\partial c}\frac{c}{\eta} - \alpha q^{-1}\left(1-\eta^{-1}\right)^{-1}\right] > 0$$

since $D^{-1} < 0$ and $\frac{\partial\eta}{\partial c}\frac{c}{\eta} < 0$.

Next, solving for dc/dtau, we use the market clearing condition:

In equilibrium, total net output (supply) is equal to total consumption (demand) as shown in equation (2.8). Then, take the total differential and solve for the effect of a change in emissions tax rate on consumption level as the following.

$$(1-\theta)q = Lc$$

By substitution for the equilibrium value of the fraction of output allocated towards abatement, θ and rearranging, this implies,

$$c = L^{-1}(1-\theta)q = L^{-1}q\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}} = L^{-1}q\tau^{-\frac{1}{\delta}}\left(\frac{w\beta}{(\delta-1)}\right)^{\frac{1}{\delta}}$$

Taking the total differential with respect to consumption, output and emissions tax rate, we obtain the following:

$$dc = L^{-1}\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}} dq + L^{-1}q\left(-\frac{1}{\delta}\right)\tau^{-\frac{1}{\delta}-1}\left(\frac{w\beta}{(\delta-1)}\right)^{\frac{1}{\delta}} d\tau$$

Dividing both sides by $d\tau$, and recognizing that $e = \left(\frac{w\beta}{\tau(\delta-1)}\right)$, this implies:

(A1.37) $$\frac{dc}{d\tau} = L^{-1}e^{\frac{1}{\delta}}\frac{dq}{d\tau} - \frac{q}{L\delta\tau}e^{\frac{1}{\delta}}$$

Since $\frac{dq}{d\tau}$ is shown to be negative in the foregoing analysis, this implies that $\frac{dc}{d\tau} < 0$.

Find the change in firm-level emission due to a change in emission tax rate:

Emission is:

$$z = eq$$

Total differentiation implies:

$$dz = qde + edq$$

Then,

$$\frac{dz}{d\tau} = q\frac{de}{d\tau} + e\frac{dq}{d\tau}$$

Therefore, the change in emission at the firm level depends on the change in emission intensity due to a change in emission tax rate (tax-induced technique effect) and the change in output due to a change in emission tax rate (tax-induced scale effect). There is no tax-induced selection effect at the firm level.

The effect of a change in emission tax on the number of firms or product varieties is given by the following:

$$\frac{dn}{d\tau} = \frac{dn}{d\tau}\frac{dq}{dq} = \frac{dn}{dq}\frac{dq}{d\tau}$$

Note that from full employment equation we have:

$$n = \frac{L}{(\alpha + \beta q)} = L(\alpha + \beta q)^{-1}$$

$$\textit{Taking the total differential:}$$

$$dn = \left\{-L(\alpha + \beta q)^{-2}\beta\right\}dq$$

$$\textit{This implies:}$$

$$\frac{dn}{dq} < 0$$

Then,

$$\frac{dn}{d\tau} = -\left\{L(\alpha + \beta q)^{-2}\beta\right\}\frac{dq}{d\tau}$$

Since $\frac{dn}{dq} < 0$, the change in the number of firms or product varieties moves in the opposite direction of the change in the output level when there is a change in emissions tax rate.

Note, the policy-induced selection effect can be written as:

$$\frac{dn}{d\tau} = \left(-(eq)\left(\frac{L\beta}{(\alpha + \beta q)^2}\right)\right)\frac{dq}{d\tau} = -(eq)\left(\frac{n\beta}{(\alpha + \beta q)}\right)\frac{dq}{d\tau} = -(en)\left(\frac{\beta q}{(\alpha + \beta q)}\right)\frac{dq}{d\tau}$$

$$\textit{where}$$

$$n = \frac{L}{(\alpha + \beta q)}$$

Trade and the Environment

The ZE line is:

$$ZE: \quad \frac{p}{w} = \tau^{\frac{1}{\delta}} \left(\frac{(w\beta)}{(\delta-1)} \right)^{-\frac{1}{\delta}} \left[\alpha q^{-1} + \beta \left(\frac{\delta}{(\delta-1)} \right) \right]$$

The market clearing condition is:

$$(1-\theta)q = Lc \quad or \quad q = \frac{Lc}{(1-\theta)}$$

Then, substituting for the equilibrium level of abatement, θ, gives:

$$q = \frac{Lc}{(1-\theta)} = \frac{Lc}{\left(\frac{(w\beta)}{\tau(\delta-1)} \right)^{\frac{1}{\delta}}}$$

Then, rewrite the ZE curve as the ZZ line:

ZZ :

$$\frac{p}{w} = \tau^{\frac{1}{\delta}} \left(\frac{(w\beta)}{(\delta-1)} \right)^{-\frac{1}{\delta}} \left[\alpha \frac{\left(\frac{(w\beta)}{\tau(\delta-1)} \right)^{\frac{1}{\delta}}}{Lc} + \beta \left(\frac{\delta}{(\delta-1)} \right) \right] = L^{-1} \frac{\alpha}{c} + \left(\frac{(w\beta)}{\tau(\delta-1)} \right)^{-\frac{1}{\delta}} \beta \left(\frac{\delta}{(\delta-1)} \right)$$

Write as:

$$ZZ: \quad \frac{p}{w} = L^{-1} \frac{\alpha}{c} + \varpi^{-1} \beta \left(\frac{\delta}{(\delta-1)} \right)$$

where

$$\varpi = \left(\frac{(w\beta)}{\tau(\delta-1)} \right)^{\frac{1}{\delta}} \quad and \quad \mathrm{B} = \beta \left(\frac{\delta}{(\delta-1)} \right)$$

Total differentiation of the ZZ curve is:

$$d\left(\frac{p}{w}\right)=\left\{(-1)c^{-2}\frac{\alpha}{L}\right\}dc=-c^{-2}\frac{\alpha}{L}dc$$

Therefore, the slope of the ZZ curve is:

$$\frac{d(ZZ)}{dc}=-c^{-2}\frac{\alpha}{L}<0$$

which implies that the ZL curve is downward sloping.

Given consumption, the wage and emission tax rates and the parameters, a change in the labor population, L, shifts the ZZ curve in a negative direction. This is shown as the following:

$$\frac{\partial(ZZ)}{\partial L}=\frac{\partial\left(\frac{p}{w}\right)}{\partial L}=-L^{-2}\frac{\alpha}{c}<0$$

Table A.2: Comparative Statics Effects of a Change in Emission Tax Rate

1.	$\frac{\partial\theta}{\partial\tau}=\frac{1}{\delta}\tau^{-1}\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}}=(\delta\tau)^{-1}e^{\frac{1}{\delta}}>0$ An increase in emissions tax rate increases the level of abatement undertaken by firms.
2.	$\frac{\partial e}{\partial\tau}=-\tau^{-2}\left(\frac{w\beta}{(\delta-1)}\right)=-\tau^{-1}\left(\frac{w\beta}{\tau(\delta-1)}\right)=-\frac{e}{\tau}<0$ An increase in emissions tax rate increases lowers emission intensity. *This is the policy-induced technique effect.*

Table A.2: Comparative Statics Effects of a Change in Emission Tax Rate Continued

3. $$\frac{dz}{d\tau}=\left(q\frac{de}{d\tau}+e\frac{dq}{d\tau}\right)<0$$

or

$$\hat{z}=\hat{e}+\hat{q}$$

A change in firm-level emission due to a change in emission tax rate depends on $\frac{de}{d\tau}$, the policy-induced technique effect and $\frac{dq}{d\tau}$, the policy-induced scale effect.

4. $$\frac{dp}{d\tau}=D^{-1}\tau^{\frac{2}{\delta}}\varpi^{-2}B\delta^{-1}\tau^{-1}q^{-1}\left[B\eta^{-1}\frac{\partial\eta}{\partial c}\frac{c}{\eta}-\alpha q^{-1}\left(1-\eta^{-1}\right)^{-1}\right]>0$$

An increase in emissions tax rate raises the price level.

5. $$\frac{dq}{d\tau}=-D^{-1}\left(1-\eta^{-1}\right)^{-2}\eta^{-1}\tau^{-1}\delta^{-1}pw^{-2}\left(\frac{\partial\eta}{\partial p}\frac{p}{\eta}+\frac{\partial\eta}{\partial c}\frac{c}{\eta}\right)<0$$

An increase in emissions tax rate leads to lower output level. *This is the policy-induced scale effect.*

6. $$\frac{dc}{d\tau}=L^{-1}e^{\frac{1}{\delta}}\frac{dq}{d\tau}-\frac{q}{L\delta\tau}e^{\frac{1}{\delta}}<0$$

A change in emissions tax rate leads to a negative change in consumption level.

7. $$\frac{dn}{d\tau}=-\left(\frac{L\beta}{\left(\alpha+\beta q\right)^{2}}\right)\frac{dq}{d\tau}>0$$

An increase in emissions tax rate depends on the scale effect, that is, on whether the effect of emissions tax leads to a contraction or expansion of output production. Since the scale effect is negative, a higher emissions tax leads to an increase in the number of firms. *This is the policy-induced selection effect.*

8. $$\frac{dZ}{d\tau}=\left(\left(eq\right)\frac{dn}{d\tau}+\left(nq\right)\frac{de}{d\tau}+\left(ne\right)\frac{dq}{d\tau}\right)\gtreqless 0$$

or

$$\hat{Z}=\left(\hat{n}+\hat{e}+\hat{q}\right)\gtreqless 0$$

An increase in emissions tax rate may increase or decrease the total level of emissions in the economy depending on the sum of the policy-induced scale, selection and technique effects.

Table A.3: The Impact of Intra-Industry Trade on the Economy

Effects Of Intra-industry Trade on:	**Note: All countries are identical**
1. Abatement (θ)	Openness to trade does not lead to a direct change on the level of the firm's abatement activity. However, a *trade-induced technique effect* occurs if trade leads to an expansion or contraction of the scale of production which leads to a rise or fall in income level. This in turn leads to either an increase or decrease in the stringency of environmental policy respectively. Firms react accordingly by increasing or reducing abatement activity to mitigate the cost of environmental compliance. This leads to a *trade-induced technique effect* if abatement affects a change in emission intensity.
2. Emission per unit output (e)	Free trade does not lead to a direct change in emission intensity. However, a *trade-induced technique effect* occurs if trade leads to an expansion or contraction of production that affects income level, which in turn leads to a change in the stringency of environmental policy. Firms lower or raise emission intensity by undertaking more or less abatement as a response to a change in environmental policy.
3. Price (p/w)	Trade implies as if there is a doubling of labor, thus the ZZ curve shifts downward which leads to a fall in price.
4. Consumption (c)	The ZZ curve shifts downward, leading to a fall in the consumption of each product variety.
5. Quantity of output (q)	Entry and exit of firms with free trade imply surviving firms take advantage of scale economies, increasing output. This is the *trade-induced scale effect.*
6. Number of Firms or Varieties (n)	As output increases and labor is fixed, the number of product varieties or firms necessarily falls with trade. *This is the trade-induced selection effect.*
7. Total emission (Z)	The total effect of intra-industry trade on total emission level is the sum of the *trade-induced scale, technique and selection effects*: $dZ = (eq)dn + (nq)de + (ne)dq$ or write in percent change: $\hat{Z} = \hat{n} + \hat{e} + \hat{q}$

Appendix B: Intra-Industry Trade and the Environment

B.1: Production in Trade-Environment Model with CES Utility Function

The profit function is the firm's revenue less labor cost, pollution taxes and abatement cost such that:

(B.1) $$\pi_i = p(1-\theta)q_i - w\alpha - w\beta q_i - \tau z_i$$

where

$$p = p_i((1-\theta_i)q_i)$$

By the substitution of equations (2.3) and (2.7) into (B.1), the following profit function is obtained:

(B.2) $$\pi_i = p_i((1-\theta_i)q_i)(1-\theta_i)q_i - W\alpha - W\beta q_i - \tau(1-\theta_i)^{\delta} q_i$$

The first order conditions for profit maximization with respect to q implies:

(B.3) $$p'(1-\theta)^2 q + p(1-\theta) - w\beta - \tau(1-\theta)^{\delta} = 0$$

Divide equation (B.3) through by $(1-\theta)$ and rearrange to obtain:

(B.4) $$p'(1-\theta)q + p - \tau(1-\theta)^{\delta-1} = \frac{w\beta}{(1-\theta)}$$

The first order conditions for profit maximization with respect to θ is:

(B.5) $$-qp'(1-\theta)q - qp + \tau\delta(1-\theta)^{\delta-1} q = 0$$

Divide (B.5) by q and rearranging, equation (B.5) can be rewritten as:

(B.6) $$p'(1-\theta)q + p - \tau\delta(1-\theta)^{\delta-1} = 0$$

Using (B.4), this implies:

(B.7) $$\theta = 1 - \left(\frac{w\beta}{\tau(\delta - 1)} \right)^{\frac{1}{\delta}}$$

The fraction of output allocated towards abatement, θ, is decreasing in wage w, and the labor coefficient β; it is increasing in the emission tax τ, and the elasticity of emission with respect to the consumption fraction of output δ.

Substituting for elasticity of demand, we can rewrite equation (B.4) as:

(B.8) $$p\left(1 - \frac{1}{\eta}\right) - \tau(1-\theta)^{\delta - 1} = \frac{w\beta}{(1-\theta)}$$

where η is the price elasticity of demand for net output.

Then by substitution of equation (B.7) into equation (B.8), the pricing equation is obtained:

(B.9) $$p\left(1 - \frac{1}{\eta}\right) = \left(\frac{\delta}{\delta - 1}\right)\left[(w\beta)^{\delta - 1}\tau(\delta - 1)\right]^{\frac{1}{\delta}}$$

Since price elasticity of demand is equal to $1/(1-\rho)$, equation (B.8) can be rewritten as:

(B.10) $$p \cdot \rho = \left(\frac{\delta}{\delta - 1}\right)\left[(w\beta)^{\delta - 1}\tau(\delta - 1)\right]^{\frac{1}{\delta}}$$

or $$p = \frac{1}{\rho}\left(\frac{\delta}{\delta - 1}\right)\left[(w\beta)^{\delta - 1}\tau(\delta - 1)\right]^{\frac{1}{\delta}}$$

Then, price is decreasing in ρ, and increasing in δ, w (wage), β (labor productivity coefficient), and τ (emission tax imposed by the government).

Free entry of firms implies that the zero profit condition is given by the following equation:

(B.11) $$p(1-\theta)q - w\alpha - w\beta q - \tau(1-\theta)^{\delta} q = 0$$

By substitution of equation (B.7) into equation (B.11) we solve for output level, as follows:

The zero profit condition is:

(B.11) $$p(1-\theta)q - w\alpha - w\beta q - \tau(1-\theta)^{\delta} q = 0$$

But price is:

$$p\left(1-\frac{1}{\eta}\right) - \tau(1-\theta)^{\delta-1} = \frac{w\beta}{(1-\theta)}$$

Rewrite as:

$$p \cdot \rho = \tau(1-\theta)^{\delta-1} + \frac{w\beta}{(1-\theta)}$$

Thus,

$$p = \frac{1}{\rho}\left\{\tau(1-\theta)^{\delta-1} + \frac{w\beta}{(1-\theta)}\right\}$$

Substitute into the Zero Profit Condition:

$$p(1-\theta)q - w\alpha - w\beta q - \tau(1-\theta)^{\delta} q = 0$$

$$\frac{1}{\rho}\left\{\tau(1-\theta)^{\delta-1} + \frac{w\beta}{(1-\theta)}\right\}(1-\theta)q - w\alpha - w\beta q - \tau(1-\theta)^{\delta} q = 0$$

Simplify by cancelling $(1-\theta)$:

$$\frac{1}{\rho}\left\{\tau(1-\theta)^{\delta} + w\beta\right\}q - w\alpha - w\beta q - \tau(1-\theta)^{\delta} q = 0$$

Divide by q:

$$\frac{1}{\rho}\left\{\tau(1-\theta)^{\delta} + w\beta\right\} - w\alpha q^{-1} - w\beta - \tau(1-\theta)^{\delta} = 0$$

Collecting terms:

$$\tau\left(1-\theta\right)^{\delta}\left[\frac{1}{\rho}-1\right]+w\beta\left[\frac{1}{\rho}-1\right]-w\alpha q^{-1}=0$$

Substituting for θ from (B.7):

$$\tau\left(1-\left(1-\left(\frac{w\beta}{\tau(1-\delta)}\right)^{\frac{1}{\delta}}\right)\right)^{\delta}\left[\frac{1}{\rho}-1\right]+w\beta\left[\frac{1}{\rho}-1\right]-w\alpha q^{-1}=0$$

Simplifying:

$$\tau\left(\left(\frac{w\beta}{\tau(1-\delta)}\right)^{\frac{1}{\delta}}\right)^{\delta}\left[\frac{1}{\rho}-1\right]+w\beta\left[\frac{1}{\rho}-1\right]-w\alpha q^{-1}=0$$

$$\tau\left(\frac{w\beta}{\tau(1-\delta)}\right)\left[\frac{1}{\rho}-1\right]+w\beta\left[\frac{1}{\rho}-1\right]-w\alpha q^{-1}=0$$

Cancel τ and collect terms:

$$\left(\frac{1}{\rho}-1\right)\left\{\left(\frac{w\beta}{(1-\delta)}\right)+w\beta\right\}-w\alpha q^{-1}=0$$

Divide by w:

$$\left(\frac{1}{\rho}-1\right)\left\{\left(\frac{\beta}{(1-\delta)}\right)+\beta\right\}-\alpha q^{-1}=0$$

Simplify:

$$\left(\frac{1}{\rho}-1\right)\left\{\left(\frac{\beta}{(1-\delta)}\right)+\frac{\beta(1-\delta)}{(1-\delta)}\right\}=\alpha q^{-1}$$

$$\left(\frac{1-\rho}{\rho}\right)\left\{\left(\frac{\beta\left(1-(1-\delta)\right)}{(1-\delta)}\right)\right\}=\alpha q^{-1}$$

$$\left(\frac{1-\rho}{\rho}\right)\left\{\left(\frac{\beta\left(\delta\right)}{(1-\delta)}\right)\right\}=\alpha q^{-1}$$

Solve for q:

$$\left(\frac{1-\rho}{\rho}\right)\left(\frac{\beta\delta}{(1-\delta)}\right)q=\alpha$$

$$\frac{(1-\rho)\beta\delta}{\rho(1-\delta)}\cdot q=\alpha$$

Thus,

(B.12) $$q=\frac{\alpha\rho(1-\delta)}{\beta\delta(1-\rho)}$$

Then, net output, $(1-\theta)q$, is the following:

(B.13) $$q^{net}=\left(\frac{w\beta}{\tau}\right)^{\frac{1}{\delta}}\left(\frac{\alpha\rho(\delta-1)^{1-1/\delta}}{\beta\delta(1-\rho)}\right)$$

To solve for the number of product varieties, we use the full-employment condition:

(B.14) $$L=\sum_{i=1}^{n}(\alpha+\beta q_i)$$

Then, solving for n, the number of varieties is:

(B.15) $$n=\frac{L}{\alpha+\beta q}$$

And by substitution of equation (B.11) into equation (B.14), obtain:

(B.16) $$n=\frac{L\delta(1-\rho)}{\alpha\left[\delta(1-\rho)+\rho(\delta-1)\right]}$$

Equation (B.15) implies that n is a constant, a function of all fixed parameters. It indicates that the number of firms or varieties is increasing in labor, L. With free trade, the consumer's range of varieties available for consumption will be $n+N$.

B.2: Pollution Supply

Government and Emissions Tax

The regulatory authority levies an emissions tax on firms to internalize the externality associated with the production of pollution.

Then, to solve for tax, insert the demand equations in (2.3) and (2.3') into (2.1) to obtain the indirect utility function:

(B.17)
$$V^H = \frac{y^\rho \left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)}{\left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)^\rho} - n\varphi z$$

where $y = w + s$ and $s = \tau \sum_{i=1}^{n} z_i = \tau n z$ by symmetry, and is a lump sum transfer.

Then, assume symmetry and write (3.11) as:

(B.18)
$$V^H = \frac{(\tau n z)^\rho \left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)}{\left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)^\rho} - n\varphi z$$

$$V^H = \frac{(\tau n z)^\rho \left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)}{\left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)^\rho} - n\varphi e q$$

$$V^H = \frac{(\tau n z)^\rho \left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)}{\left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)^\rho} - n\varphi \left(\frac{w\beta}{\tau(\delta-1)}\right) q$$

$$V^H = \frac{(\tau n z)^\rho \left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)}{\left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)}\right)^\rho} - n\varphi \tau^{-1} \left(\frac{w\beta}{(\delta-1)}\right) q$$

Then, environmental policy will be given by maximizing equation (3.12) with respect to emission tax, τ. The first order condition is:

$$\frac{\partial V^H}{\partial \tau} = \frac{\rho \tau^{\rho-1} (nz)^\rho \left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)} \right)}{\left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)} \right)^\rho} + n\varphi \tau^{-2} \left(\frac{w\beta}{(\delta-1)} \right) q = 0$$

Then,

$$\frac{\partial V^H}{\partial \tau} = \frac{\rho \tau^{\rho-1} (nz)^\rho \left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)} \right)}{\left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)} \right)^\rho} = -n\varphi \tau^{-2} \left(\frac{w\beta}{(\delta-1)} \right) q$$

$$Let\ \psi = \frac{\left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)} \right)}{\left(np^{\rho/(\rho-1)} + n^* p^{*\rho/(\rho-1)} \right)^\rho}$$

Then,

$$-\tau^2 \tau^{\rho-1} \psi = n\varphi\rho^{-1} \left(\frac{w\beta}{(\delta-1)} \right) q$$

$$-\tau^{1+\rho} = \left(\frac{1}{\psi} \right) \varphi\rho^{-1} \left(\frac{w\beta}{(\delta-1)} \right) q$$

(B.19) $$-\tau = \left[\left(\frac{1}{\psi} \right) \varphi\rho^{-1} \left(\frac{w\beta}{(\delta-1)} \right) q \right]^{\frac{1}{1+\rho}}$$

Equation (B.19) indicates that the emission tax is a function of the marginal disutility for pollution, the number of product varieties produced at home and abroad, price, wage and the fixed parameters. Since wage is income from working, then emission tax is a function of income. Equation (B.19) shows that an increase in the wage rate increases the emission tax rate:

$$-\tau = \left[\left(\frac{1}{\psi}\right)\varphi\rho^{-1}\left(\frac{w\beta}{(\delta-1)}\right)q\right]^{\frac{1}{1+\rho}} = -w^{-(1+\rho)}\left[\left(\frac{1}{\psi}\right)\varphi\rho^{-1}\left(\frac{\beta}{(\delta-1)}\right)q\right]^{\frac{1}{1+\rho}}$$

(B.20) $$\frac{\partial\tau}{\partial w} = -\left(-(1+\rho)\right)w^{-1-(1+\rho)}\left[\left(\frac{1}{\psi}\right)\varphi\rho^{-1}\left(\frac{\beta}{(\delta-1)}\right)q\right]^{\frac{1}{1+\rho}}$$

$$\frac{\partial\tau}{\partial w} = (1+\rho)w^{-(2+\rho)}\left[\left(\frac{1}{\psi}\right)\varphi\rho^{-1}\left(\frac{\beta}{(\delta-1)}\right)q\right]^{\frac{1}{1+\rho}} > 0$$

Thus, equation (B.20) shows an increase in the wage rate which increases income, leads to a rise in the stringency of environmental regulation.

Equation (B.19) shows the Samuelson rule, which can be written as:

$$\tau = -\left[\left(\frac{1}{\psi}\right)\varphi\rho^{-1}\left(\frac{w\beta}{(\delta-1)}\right)q\right]^{\frac{1}{1+\rho}}$$

The term on the right hand side of the equation indicates the marginal damage of pollution for each consumer. Note that the number of product varieties and the level of output are functions of fixed parameters, including labor. Thus, emission tax rate varies with economic conditions and can be written to be as:

(B.21) $$\tau = \tau\left(n, n^{*}, p, p^{*}; \varphi, w, L, \beta, \delta, \rho, \alpha\right)$$

Table B.1: Comparative Statics Effects of a Change in Emission Tax Rate in the CES Model of Intra-industry Trade and Environment

1. $$\frac{\partial\theta}{\partial\tau} = \frac{1}{\delta}\tau^{-1}\left(\frac{w\beta}{\tau(\delta-1)}\right)^{\frac{1}{\delta}} = (\delta\tau)^{-1} e^{\frac{1}{\delta}} > 0$$

   An increase in emissions tax rate increases the level of abatement undertaken by firms.

2. $$\frac{\partial e}{\partial\tau} = -\tau^{-2}\left(\frac{w\beta}{(\delta-1)}\right) = -\tau^{-1}\left(\frac{w\beta}{\tau(\delta-1)}\right) = -\frac{e}{\tau} < 0$$

   An increase in emissions tax rate increases lowers emission intensity. *This is the policy-induced technique effect.*

3. $$\frac{dz}{d\tau} = \left(q\frac{de}{d\tau} + e\frac{dq}{d\tau}\right) < 0$$

   or

   $$\hat{z} = \hat{e} + \hat{q}$$

   A change in firm-level emission due to a change in emission tax rate depends on $\frac{de}{d\tau}$, the policy-induced technique effect and $\frac{dq}{d\tau}$, the policy-induced scale effect.

4. $$\frac{\partial p}{\partial\tau} = \tau^{\frac{1-\delta}{\delta}}\left(\rho(\delta-1)\right)^{-1}\left[(w\beta)^{\delta-1}(\delta-1)\right]^{\frac{1}{\delta}} > 0$$

   An increase in emissions tax rate raises the price level.

5. $$\frac{\partial q}{\partial\tau} = 0$$

   An increase in emissions tax rate does not affect the scale of production. *The policy-induced scale effect is neutral.*

Table B.1: Comparative Statics Effects of a Change in Emission Tax Rate in the CES Model of Intra-industry Trade and Environment Continued

6.	$\frac{\partial q^{net}}{\partial \tau} = -\tau^{-\left(\frac{1+\delta}{\delta}\right)} \frac{(w\beta)^{\frac{1}{\delta}}}{\delta} \left(\frac{\alpha\rho(\delta-1)^{1-1/\delta}}{\beta\delta(1-\rho)} \right) < 0$ An increase in emissions tax rate leads to a decrease in net output level.
7.	$\frac{\partial c}{\partial \tau} = -\tau^{-\frac{(1+\delta)}{\delta}} \left(\frac{w\beta}{(\delta-1)} \right)^{\frac{1}{\delta}} L^{-1} q < 0$ A change in emissions tax rate leads to a negative change in consumption level.
8.	$\frac{\partial n}{\partial \tau} = 0$ An increase in emissions tax rate does not affect the equilibrium number of firms in the economy. *The policy-induced selection effect is neutral.*
9.	$\frac{dZ}{d\tau} = \left((eq)\frac{dn}{d\tau} + (nq)\frac{de}{d\tau} + (ne)\frac{dq}{d\tau} \right) \gtrless 0$ or $\hat{Z} = (\hat{n} + \hat{e} + \hat{q}) \gtrless 0$ An increase in emissions tax rate may increase or decrease the total level of emissions in the economy depending on the sum of the policy-induced scale, selection and technique effects.

Table B.2: The Impact of Intra-Industry Trade on the Economy with CES utility function.

Effects Of Intra-industry Trade on	**(Note: All countries are identical)**
1. Abatement (θ)	Openness to trade does not lead to a direct change on the level of the firm's abatement activity. The *trade-induced technique effect is neutral.*
2. Emission per unit output (e)	Free trade does not lead to a direct change in emission intensity. However, a *trade-induced technique effect* occurs if trade leads to a change in the stringency of environmental policy. Firms lower or raise emission intensity by undertaking more or less abatement as a response to a change in environmental policy.
3. Price (p/w)	In the CES model of trade and environment, product price is unchanged under the free trade regime.
4. Consumption (c)	The opening of trade in the integrated world economy leads to imports and exports which implies there is a greater number of product varieties available for consumption. However, the scale of production, the level of abatement and the price level is unchanged with open trade, thus there is no change in the level of consumption of domestic product varieties.
5. Quantity of output (q)	Constant elasticity of substitution of the utility function leads to fixed equilibrium gross output level. This is the *neutral trade-induced scale effect.*
6. Number of Firms/Varieties (n)	As output is unchanged, the number of product varieties or firms is also unchanged with trade. This is the *neutral trade-induced selection effect.*
7. Total emission (Z)	The total effect of intra-industry trade on total emission level is the sum of the *trade-induced scale, technique and selection effects*: $$dZ = (eq)dn + (nq)de + (ne)dq$$ or write in percent change: $$\hat{Z} = \hat{n} + \hat{e} + \hat{q}$$

Appendix C: How Does Intra-industry Trade Affect the Environment?

C.1 Reduced Form Equation

The scale effect in the model can be further decomposed into three effects: (i) the effect of labor force, L, (ii) the effect of consumption or demand, c, and (iii) the effect of the fraction of output allocated towards production of goods rather than towards abatement, $(1-\theta)$. Equation (3.9) indicates that:

$$c = c\left(n, n^{*}, p, y, t, \tau; p^{*}, \rho, \delta, w\right)$$

Then, the scale effect as represented by demand/consumption is given by:

(C.1) $$\hat{c} = \varepsilon_{cn}\hat{n} + \varepsilon_{cN}\hat{n}^{*} + \varepsilon_{cp}\hat{p} + \varepsilon_{cy}\hat{y} + \varepsilon_{c\tau}\hat{\tau} + \varepsilon_{cP}\hat{p}^{*} + \varepsilon_{cw}\hat{w} + \varepsilon_{c\rho}\hat{\rho} + \varepsilon_{c\delta}\hat{\delta}$$

From equation (3.6), producer price is a function of emission tax and the fixed parameters including wage. Then, price can be reduced in terms of its primitive factors:

(C.2) $$\hat{p} = \varepsilon_{p\tau}\hat{\tau} + \varepsilon_{pp^{*}}\hat{p}^{*} + \varepsilon_{pw}\hat{w} + \varepsilon_{p\rho}\hat{\rho} + \varepsilon_{p\delta}\hat{\delta}$$

Lastly, pollution demand and supply are combined to obtain the final reduced form equation where the technique effect will be represented by basic determinants obtained through the efficient tax equation. From equation (3.15), efficient tax is a function wage (income), the number of product varieties, producer and world prices, and the fixed parameters for preferences and emissions, such that:

(C.3) $$\tau = \tau\left(n, n^{*}, p, p^{*}; \varphi, w, L, \beta, \delta, \rho, \alpha\right)$$

From equation (3.9) and (2.10), emission per unit output can be solved for and written as:

(C.4) $$e = e\left(\tau; \beta, \delta, w\right)$$

Then, the effect of per unit emission can be written as:

(C.5) $$\hat{e} = \varepsilon_{e\tau}\hat{\tau} + \varepsilon_{ew}\hat{w} + \varepsilon_{e\beta}\hat{\beta} + \varepsilon_{e\delta}\hat{\delta}$$

From equation (3.5), the effect of abatement can be written as:

(C.6) $$\hat{\theta} = \varepsilon_{\theta\tau}\hat{\tau} + \varepsilon_{\theta w}\hat{w} + \varepsilon_{\theta\beta}\hat{\beta} + \varepsilon_{\theta\delta}\hat{\delta}$$

Thus, from equation (3.10), the pollution demand equation is:

(C.7) $$\hat{Z} = \hat{n} + \hat{L} + \hat{c} + \hat{e} - (1 \hat{-} \theta)$$ *Pollution demand equation*

Let the Scale effect be defined by total domestic consumption:

$$\hat{S} = \hat{L} + \hat{c} - (1 \hat{-} \theta)$$

Then, rewrite (C.7) as:

(C.8) $$\hat{Z} = \hat{n} + \hat{S} + \hat{e}$$

Substituting for emission intensity using equation (C.5) to obtain:

(C.9) $$\hat{Z} = \hat{n} + \hat{S} + \left\{\varepsilon_{e\tau}\hat{\tau} + \varepsilon_{ew}\hat{w} + \varepsilon_{e\beta}\hat{\beta} + \varepsilon_{e\delta}\hat{\delta}\right\}$$

Pollution supply from equation (3.15) implies:

(C.10)

$$\hat{\tau} = \varepsilon_{\tau p}\hat{n} + \varepsilon_{\tau n*}\hat{n}^{*} + \varepsilon_{\tau p}\hat{p} + \varepsilon_{\tau p*}\hat{p}^{*} + \varepsilon_{\tau\varphi}\hat{\varphi} + \varepsilon_{\tau w}\hat{w} + \varepsilon_{\tau L}\hat{L} + \varepsilon_{\tau\beta}\hat{\beta} + \varepsilon_{\tau\delta}\hat{\delta} + \varepsilon_{\tau\alpha}\hat{\alpha} + \varepsilon_{\tau\rho}\hat{\rho}$$

Substituting (C.10) into (C.9) implies:

(C.11)

$$\hat{Z} = \hat{n} + \hat{S} + \varepsilon_{e\tau}\hat{\tau} + \varepsilon_{ew}\hat{w} + \varepsilon_{e\beta}\hat{\beta} + \varepsilon_{e\delta}\hat{\delta}$$

$$\hat{Z} = \hat{n} + \hat{S} + \varepsilon_{e\tau}\begin{Bmatrix} \varepsilon_{\tau p}\hat{n} + \varepsilon_{\tau n*}\hat{n}^{*} + \varepsilon_{\tau p}\hat{p} + \varepsilon_{\tau p*}\hat{p}^{*} + \varepsilon_{\tau\varphi}\hat{\varphi} + \\ \varepsilon_{\tau w}\hat{w} + \varepsilon_{\tau L}\hat{L} + \varepsilon_{\tau\beta}\hat{\beta} + \varepsilon_{\tau\delta}\hat{\delta} + \varepsilon_{\tau\alpha}\hat{\alpha} + \varepsilon_{\tau\rho}\hat{\rho} \end{Bmatrix} + \varepsilon_{ew}\hat{w} + \varepsilon_{e\beta}\hat{\beta} + \varepsilon_{e\delta}\hat{\delta}$$

Open bracket and collecting terms:

$$\hat{Z} = \hat{n} + \hat{S} + \varepsilon_{e\tau}\varepsilon_{\tau p}\hat{n} + \varepsilon_{e\tau}\varepsilon_{\tau n*}\hat{n}^{*} + \varepsilon_{e\tau}\varepsilon_{\tau p}\hat{p} + \varepsilon_{e\tau}\varepsilon_{\tau p*}\hat{p}^{*} + \varepsilon_{e\tau}\varepsilon_{\tau\varphi}\hat{\varphi} + \varepsilon_{e\tau}\varepsilon_{\tau L}\hat{L}$$
$$+\varepsilon_{e\tau}\varepsilon_{\tau\alpha}\hat{\alpha} + \varepsilon_{e\tau}\varepsilon_{\tau\rho}\hat{\rho} + \varepsilon_{e\tau}\varepsilon_{\tau w}\hat{w} + \varepsilon_{ew}\hat{w} + \varepsilon_{e\tau}\varepsilon_{\tau\beta}\hat{\beta} + \varepsilon_{e\beta}\hat{\beta} + \varepsilon_{e\tau}\varepsilon_{\tau\delta}\hat{\delta} + \varepsilon_{e\delta}\hat{\delta}$$

Rearranging:

$$\hat{Z} = \left(1 + \varepsilon_{e\tau}\varepsilon_{\tau p}\right)\hat{n} + \hat{S} + \varepsilon_{e\tau}\varepsilon_{\tau n*}\hat{n}^{*} + \varepsilon_{e\tau}\varepsilon_{\tau p}\hat{p} + \varepsilon_{e\tau}\varepsilon_{\tau p*}\hat{p}^{*} + \varepsilon_{e\tau}\varepsilon_{\tau\varphi}\hat{\varphi} + \varepsilon_{e\tau}\varepsilon_{\tau L}\hat{L}$$
$$+\varepsilon_{e\tau}\varepsilon_{\tau\alpha}\hat{\alpha} + \varepsilon_{e\tau}\varepsilon_{\tau\rho}\hat{\rho} + \left(\varepsilon_{e\tau}\varepsilon_{\tau w} + \varepsilon_{ew}\right)\hat{w} + \left(\varepsilon_{e\tau}\varepsilon_{\tau\beta} + \varepsilon_{e\beta}\right)\hat{\beta} + \left(\varepsilon_{e\tau}\varepsilon_{\tau\delta}\hat{\delta} + \varepsilon_{e\delta}\right)\hat{\delta}$$

Substitute for producer price in equation (C.11) and obtain the reduced form equation:

(C.12) $\hat{Z} = \Pi_1\hat{n} + \Pi_2\hat{S} + \Pi_3\hat{w} + \Pi_4\hat{n}^{*} + \Pi_5\hat{p}^{*} + \Pi_6\hat{L} + \Pi_7\hat{\rho} + \Pi_8\hat{\beta} + \Pi_9\hat{\delta} + \Pi_{10}\hat{\varphi} + \Pi_{11}\hat{\alpha}$

We adopt a parsimonious reduced form to exclude the effects of fixed parameters, namely, $\rho, \alpha, \beta, \delta, \varphi$, and assume these as country-specific effects. We note that the effect of the number of imported product varieties multiplied by foreign price level is the value of imports. We sum the two effects to indicate the amount of imported goods and denote the sum as M . Further, we note that the effect of labor and wage can be summed as the effect of total income, and denote it as Y . Then, the following reduced form equation is obtained:

(C.13) $\hat{Z} = \Pi_1\hat{n} + \Pi_2\hat{S} + \Pi_3\hat{Y} + \Pi_4\hat{M}$

C.2 Calculating Real Capital Stock Using Method in Leamer (1984, pp. 233):

Let

I_t = gross domestic investment in year t in units of home currency;

P_t^b = implicit gross domestic investment deflator at time t with base year b, $P_b^b = 1.0$;

e_t = exchange rate in time period t, dollars per unit of home currency;

δ = rate of depreciation

The real capital stock at the end of year t in year is calculated by converting "investment flows year by year into dollars and use the U.S. gross domestic investment (GDI) deflator to convert to constant dollars:

$$K_t = P_t^b(\$)\sum_{j=0}^{t}(1-\delta)^{t-j}\left(I_j e_j / P_j^b(\$)\right)$$

Asset life of 15 years is selected. The corresponding rate of depreciation commensurate with double declining balance method is 13.3%."

C.3 Calculation of Marginal Effects

The partial effect of a change in the selection effect on SOx in Model B is (see Wooldridge (2003) pp.):

$$\%\Delta \hat{SOx} = 100\left[\exp\left(\alpha_{firm}\cdot 1\right)-1\right] = 100\left[\exp(0.548)-1\right] = 72.97\%$$

The partial effect of a change in the composition effect (capital intensity) on SOx in Model B is (see Wooldridge (2003) pp. 192-193):

$$\%\Delta \hat{SOx} = 100\left[0-2(-0.036)5.275\right] = \left\{100\left[2(0.036)5.275\right]\right\}(6.275-5.275) = 37.98\%.$$

C.4 SUMMARY STATISTICS

FIXED EFFECTS (FE) AND RANDOM EFFECTS (RE) ESTIMATION USING STATA:

```
log:  C:\Users\Sarma\Documents\EMPIRICAL ANALYSIS\DOFILES\OECD\NOV
2009\OECD Trade-Environ 11.05.09.smcl

. use "C:\Users\Sarma\Documents\EMPIRICAL ANALYSIS\DATA\OECD
Pollution\OECD Data INTERACTIONS 8.12.09.dta"

.
***SUMMARY STATISTICS***

. sum  office countrycode country year company avewgnp fdi sox nox  voc
land2km pop cgnp rgdpl rgdptt openk ppp  labor k POPDNSTY SOXKM NOXKM
VOCKM logSOXKM logNOXKM logVOCKM _Iyear_1996 _Iyear_1997 _Iyear_1998
_Iyear_1999 _Iyear_2000 _Iyear_2001 _Iyear_2002  _Iyear_2003
_Iyear_2004 GNPCAP GNP RELINC KLINC TIRINC COKM ATRANSKM COKMSQ ATRANSP
LANDKM GrDP GrDPKM GrDPKMSQ KapL KapLSQ GNPcap GNPcapMA INCapL INCapLSQ
AWGNP GrNP KapLINC COM COMKM FDIKM POP POPDNSY TID INCAPD COMD TICOMD
TINCD INCSQD TICSQD COMKMSQ GDPINCD
```

Variable	Obs	Mean	Std. Dev.	Min	Max
office	0				
countrycode	259	15.57143	8.866239	1	30
country	0				
year	259	1999.517	2.869697	1995	2004
company	259	886.3205	1502.627	18	8851
avewgnp	259	2.26e+10	2.09e+09	1.96e+10	2.61e+10
fdi	257	2.928871	3.147977	-3.597555	23.10155
sox	253	1327.166	2967.182	7.4	17182
nox	253	1607.198	3904.295	25.9	22405
voc	253	1337.149	3102.822	7.1	19577
land2km	259	1283477	2698198	39770	9161923
pop	259	42241.79	58511.56	267.478	295409.6
cgnp	259	98.93482	2.437064	92.53037	108.3746
rgdpl	259	20314.07	7608.587	5080.958	36100.44
rgdptt	259	20316.29	7513.61	5097.181	36196.11
openk	259	70.31149	30.51214	17.065	186.7788
ppp	259	14891.72	97543.08	.6384608	911798.4
labor	259	2.01e+07	2.97e+07	152790.9	1.52e+08
k	220	1.33e+12	2.45e+12	7.55e+09	1.16e+13
POPDNSTY	259	.1151543	.1097338	.0023551	.4852282
SOXKM	253	.0023544	.0023263	.0000738	.0141053
NOXKM	253	.0029997	.0026903	.0001768	.0138711
VOCKM	253	.0025026	.0019346	.0000708	.0081169
logSOXKM	253	-6.750883	1.394456	-9.513943	-4.261206
logNOXKM	253	-6.274315	1.081451	-8.64038	-4.27795
logVOCKM	253	-6.451888	1.160987	-9.555327	-4.813805
_Iyear_1996	259	.1003861	.3010959	0	1
_Iyear_1997	259	.1003861	.3010959	0	1

_Iyear_1998	259	.1003861	.3010959	0	1
_Iyear_1999	259	.1003861	.3010959	0	1
_Iyear_2000	259	.1003861	.3010959	0	1
_Iyear_2001	259	.1003861	.3010959	0	1
_Iyear_2002	259	.1003861	.3010959	0	1
_Iyear_2003	259	.1003861	.3010959	0	1
_Iyear_2004	259	.1003861	.3010959	0	1
GNPCAP	259	2014072	768892.9	514145.9	3623461
GNP	259	9.39e+10	1.85e+11	5.45e+08	1.07e+12
RELINC	259	4.159284	8.167973	.0278396	51.06895
KLINC	220	6.95e+15	1.45e+16	2.68e+13	8.19e+16
TIRINC	259	176.3229	215.8261	1.811234	1358.609
COKM	259	.0028064	.0039876	.000079	.0211579
ATRANSKM	259	1.146915	1.294471	.0290214	7.267563
COKMSQ	259	.0000237	.0000616	6.25e-09	.0004477
ATRANSP	259	5.849271	15.67781	.01817	95.66226
LANDKM	259	12.83477	26.98198	.3977	91.61923
GrDP	259	9.39556	18.36956	.0561082	106.6441
GrDPKM	259	2.241202	2.339727	.0533382	8.938198
GrDPKMSQ	259	10.47617	17.76185	.002845	79.89139
KapL	220	5.274884	2.3053	1.079551	11.80081
KapLSQ	220	33.11465	29.33276	1.165431	139.259
GNPcap	259	2.014072	.7688928	.5141459	3.623461
GNPcapMA	257	2.007256	.7240291	.5400245	3.521008
INCapL	256	2.001342	.7192028	.5400245	3.467017
INCapLSQ	256	4.520604	2.788162	.2916265	12.0202
AWGNP	259	2.264583	.2085505	1.957	2.612
GrNP	259	9.388832	18.46268	.0544821	107.0405
KapLINC	220	69.50029	144.6858	.2681757	819.055
COM	253	6.353096	18.23276	.0222	108.929
COMKM	253	.8179843	.5549844	.0221446	2.604412
FDIKM	257	2.390672	5.230807	-8.486001	53.06591
POP	259	42.24179	58.51156	.267478	295.4096
POPDNSY	259	11.51543	10.97339	.2355064	48.52282
TID	259	2.55e-06	30.51214	-53.24649	116.4673
INCAPD	256	4.30e-07	.7192028	-1.461318	1.465675
COMD	253	3.78e-08	.5549844	-.7958397	1.786428
TICOMD	253	-3.177935	9.697517	-41.88528	23.58792
TINCD	256	-5.952525	25.15625	-112.6293	71.36241
INCSQD	256	-3.01e-07	2.788162	-4.228978	7.4996
TICSQD	256	-22.54219	96.23718	-401.9096	208.7931
COMKMSQ	253	.9758886	1.140806	.0004904	6.782964
GDPINCD	256	.3720973	1.303684	-3.169328	3.26564

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